FINAL REPORT

Adjustable Back Angle Controller (ABAC)

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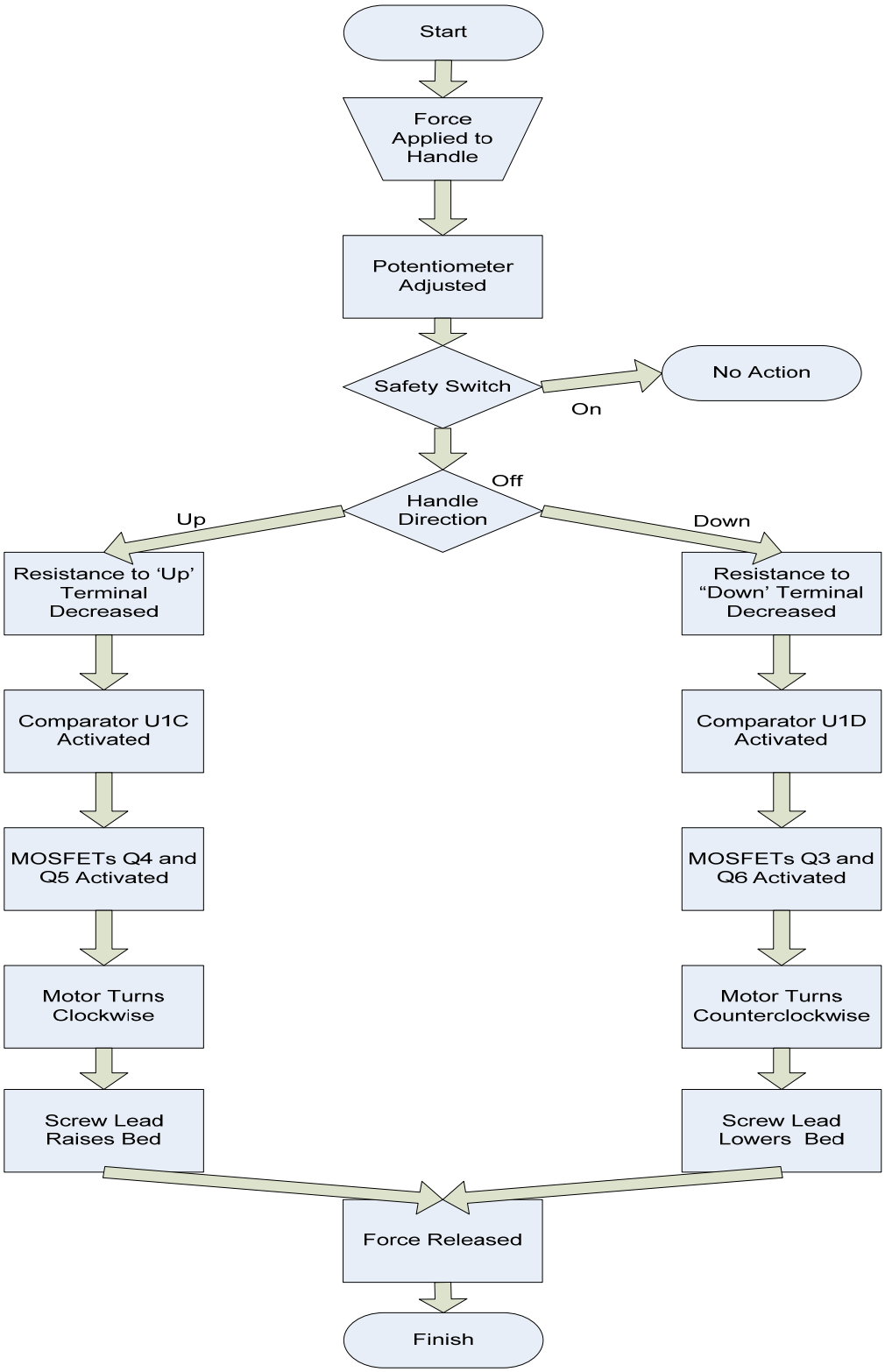
Abstract

The Rehabilitation Engineering Research Center (RERC) on Accessible Medical Instrumentation (AMI) is sponsoring the 2006-2007 National Student Design Competition. The proposed design is for an Accessible Power-Assist Hospital Bed Back Angle Controller which accommodates a wide range of patients and users of all disabilities. The basic design consists of a lever handle that controls a circuit which powers a mechanical actuator attached to the back of a bed to adjust the angle. The actuator will keep a low profile in the back so that it can fit neatly under the back of the bed and still have the bed lie completely flat. This is possible with a scissor jack that can collapse easily and it is operated by a motor which turns a screw rod to provide a smooth lift. The key features to this device are its safety lock to prevent accidental movement, the control lever which increases the speed with the amount of force applied to it, and the intuitive approach to operating the handle such that lifting the handle will give the sensation of lifting the back angle upwards and visa versa. The handle design itself will be large and easy to grip or find for those with poor vision or arthritis in the hand. There is no confusing interface or technology associated with this device. The motivation of the project is to build a totally accessible device to anyone using it.

13. Introduction

Nursing is among one of the highest risk occupations for the development of back pain and injuries. Currently 17% of nurses experience chronic back pain due to working in a hospital setting. 36% of these back injuries in nurses can be contributed to patient handling. In addition to the back pain, women are also twice as likely to contract musculoskeletal disorders from the following work tasks: repeatedly lifting greater than 7 lbs, lifting patients more than 10 times per hour, making beds normally or often, and pushing beds or trolleys more than 10 minutes per day [1]. These daily tasks cannot be avoided; however, by the implementation of an automatic adjustable bed, nurses will incur less stress on their back during the adjustment of the patient.

Patients that suffer from back pain, obesity, and other debilitating diseases, require an inclined bed back to relieve pain or provide easy access to the bed. Current technology includes an adjustable bed back with a remote control that is accessible for both the patient and the caretaker. However, this does not accommodate users of all disabilities. For example, a patient with limited sight may find it difficult to find the remote or press the correct buttons to operate the bed. Some of the current beds that may operate at higher speeds are rough or jerky when stopped in position. This erratic movement also occurs in beds that have more than one speed.



Flow Chart 1: Optimal Flow Chart

The Adjustable Back Angle Controller (ABAC) will improve upon the current methods of adjusting a bed. This device will be controlled with a force sensitive handle located on the most accessible side of the bed. The basic concept of adjusting the back angle will take the input force on the handle and adjust the speed proportional to the force applied to the handle, i.e., more force on the handle outputs a faster speed to raise or lower the back angle. This concept works by adjusting the voltage supplied to a linear actuator with a potentiometer in the joint of the handle. This design will accommodate those with limited mobility and control; as well as prevent injuries to caretakers that attempt to sit the patients upright. The variable speed motor will control the actuator from zero to a safe maximum speed. This will allow for a smoother operation while still offering speedy adjustments when necessary. Overall this device will be user-friendly, smoother in operation, and less time consuming, making the operation less stressful. This operation is summarized in Flow Chart 1, previous page.

13.1. Background

The clients that this device is being designed for have a wide range of disabilities. The first client is a 60 year old male that suffers from chronic back pain due to his previous profession of 30 years as a home health nurse that required heavy handling to help the patients sit up-right in bed. This client has mild hearing loss and suffers from carpal tunnel syndrome. The second client is a 69 year old retired woman that sleeps in a hospital bed. She has Parkinson's disease with some tremors and as a result has limited mobility and dexterity. The third client is a 31 year old lady who was recently in an automobile accident that resulted in partial paralysis of her right side. This is inconvenient because she is right handed and she doesn't want a lot of complicated medical devices in her room. The fourth client is an 86 year old that is deaf, has severe arthritis, and heart problems so that she is confined to a bed. Her 11 year old grandson has a fascination with electronics and helps her with her therapy and helps her sit up in bed. The last few client restrictions are that they are visually impaired. These clients have difficulty finding and using the current *full electric hand pendant* (Figure 2) due to its small size and confusing interface. All of the clients must be able to operate this prototype device with ease.

13.2. Purpose of the project

A large number of people encounter difficulty adjusting themselves in hospital beds due to their physical limitations. This would apply to those patients with limited mobility and dexterity associated with conditions such as Parkinson's disease, paralysis, arthritis, obesity, and other disabilities. The

problem with current powered hospital beds is they have a slow constant velocity and use open-loop controls to set the back angle. These controls require a certain level of dexterity that some users may not have. This device needs to accommodate the user's handicap (whether it is the patient or the care taker operating the device), and allow for them to be easily adjusted.

13.3. Previous Work Done By Others

Current designs of adjustable beds with back angle controllers. Most competitors offer an open-loop switch which adjusts the bed at a constant rate. Below are some similar products on the market.

13.3.1. Products

Figure 1: Invacare Adjustable Hospital Bed (Invacare©)[1]

This product is a fully electric adjustable bed, which adjusts the legs and back in a similar manner to patent# 7,058,999.

Figure 2: Full-electric Hand Pendent (Invacare©)[1]

This is the controller to the Invacare Adjustable Hospital Bed. It uses a series of open-loop switches to adjust the legs and back of the bed.

Figure 3: Air-powered Adjustable bed (ProBed©)[2]

This is an adjustable bed, which uses inflatable pillows to lift the legs and back independently.

Figure 4: Flex-A-Bed Base (Flex-A-Bed©)[3]

The Flex-A-Bed Base is the basic frame which supports any type of mattress and adjusts the bed electronically.

13.3.2. Patent Search Results

Patent Number

6,000,077 Single Motor Fully Adjustable Bed

A drive unit for adjustable beds of the type which have movable head and leg sections, and adjustable height, comprises a unidirectional, rotary motor, and a drive shaft for each adjustable bed function. The drive shafts are selectively rotated in opposite directions by the motor. A pair of solenoids operable couples

the motor with the drive shafts, interchangeably, or alternatively with a linear tracking gear, and thereby adjust the configuration of the bed.[4]

6,230,344 Adjustable Bed

The invention provides an adjustable bed frame having a main support including head and foot ends. The support is movable between raised and lowered positions and independent first and second elevating mechanisms are coupled to the main support. The mechanisms are spaced from one another on the main support to carry the bed frame on a support surface. An electrical supply system provides power to actuate the mechanisms to change the height of the main support above the support surface and a controller is coupled to the supply system to selectively activate the first and second elevating mechanisms to move the main support between raised and lowered positions. DC motors and worm drives are used independently to drive the elevating mechanisms and stops are provided at the raised and lowered positions to ensure that the main support is horizontal in the raised and lowered positions. [4]

7,058,999 Electric bed and control apparatus and control method therefor

In (.alpha., .beta.) coordinates defined by a back angle .alpha. and a knee angle .beta., a pattern that connects between a coordinate point (0, 0) at which each of a back bottom and a knee bottom is horizontal and a coordinate point (.alpha..sub.0, .beta..sub.0) which is a final reaching point for a back lift-up operation and at which the back bottom is lifted up by a plurality of points is set, an optimal pattern which provides less slipperiness and less oppressive feeling is acquired beforehand, and a control section moves the back bottom and the knee bottom along the optimal pattern. This reliably prevents a carereceiver from slipping, regardless of subjective judgment by an operator or a carergiver, at the time of performing a back lift-up operation and back lift-down operation of an electric bed. It is therefore possible to prevent pressure from being applied onto the abdominal region and chest region of the carereceiver, thus relieving the carereceiver and caregiver of the burden.

13.4. Map for the rest of the report

The rest of the report consists of the subunits of the previous designs, the optimal design layout, reason why the optimal design has been chosen, realistic constraints, safety issues, impact of engineering solutions, lifelong learning, budget and timeline, contributions of each team member and a short conclusion of this project.

14. Project Design

In this section there is a brief objective describing each design and its corresponding subunits. The optimal design was chosen because it integrates the most advantageous components of each alternative design. For example, the original idea of a hydraulic system is much more expensive than the latest electromechanical system. Also, with the manufacturability of the hydraulic system, it can get really messy and complicated trying to enclose the pipes without any leaks. The sustainability of the system is then weakened and cannot hold the load up with the pressure. In an electromechanical system, the parts are easily acquired and assembled. Also, the lifting force will not fade because it is dependent on the power source as opposed to hydraulic pressure.

14.1. Design Alternative

14.1.1. Design 1

14.1.1.1. Objective

The objective of this first design was to experiment with a hydraulic lever system. The idea behind this was to have a smooth and quiet operating system with stability to lift the patient. Since hydraulics is used in many industrial settings, there was no doubt in having enough power for this application. However, concerns about the quietness of the motor and cleanliness for hospital operations arose and caused this design to be reevaluated for the future alternative designs.

14.1.1.2. Control Lever

The control lever will consist of three main parts; a lever, two hydraulic control valves, and resistance springs. The lever will be approximately 2 feet long, and will be in the shape of a flattened "S". Figure 1 shows the basic shape which is designed to keep the majority of the control lever below the surface of the bed, out of the way of both the patient and the care-giver, while still allowing easy access to the patient within the bed. The lever will be used to operate the two hydraulic control valves. The two valves will control the amount and direction of the flow to the hydraulic piston. When the lever is moved one way, it will open one of the valves. This will allow the flow in the hydraulic lines to travel into the piston, driving it in one direction. If the lever is moved in the other direction, the other valve will be opened causing the piston to be driven in the opposite direction. Depending on the amount of deflection on the lever, the corresponding valve will be opened to a varying degree. This allows for control of the amount of hydraulic flow to the piston which will control the force output

of the piston. With a greater lever displacement, the valve will be opened more forcing the piston up with a greater force. The resistance springs serve a two fold function. First of all, they will return the lever to its zero position, which will allow both valves to be completely closed when not in operation. Second, the springs will provide the proper resistance so that a specific force will be required to displace the lever a specified amount. Therefore, the greater force applied to the lever, the greater opening in the valve and a greater output force to the bed back.

14.1.1.3. Lever

The lever will be the object moved by the user to operate the Adjustable Back Angle Controller. Its shape will be ergonomic, so as to make operation of the devise as simple and comfortable as possible. One innovation is the "S" shape which has been incorporated in Figure 5, next page. This shape is designed to keep the majority of the control lever out of the way, but allow both the patient and caretaker to comfortably work the device. This should also help reduce the occurrences of the handle being bumped, since only a fraction of it will be above the protection of the bed mattress. Another feature is a safety lock, which will be built into the handle. In the occurrence of the lever being accidentally bumped, this safety switch will prevent the bed from operating. The safety switch (similar in appearance to a hand brake on a bicycle) will unlock the lever when it is depressed. It will be placed on the under side of the lever so that it will not be accidentally triggered in the event of an accidental force being applied from the top of the handle, such as the patient rolling over on it, or a visitor sitting on it. The safety switch will operate by means of a clamp on the lever to oppose any accidental movements. When the safety switch is held down completely, this clamp will release the lever, allowing the user, be it the patient or a caretaker, to operate the bed. The safety switch will also only require as little as one pound of force to unlock it so that all users will be able to operate it.

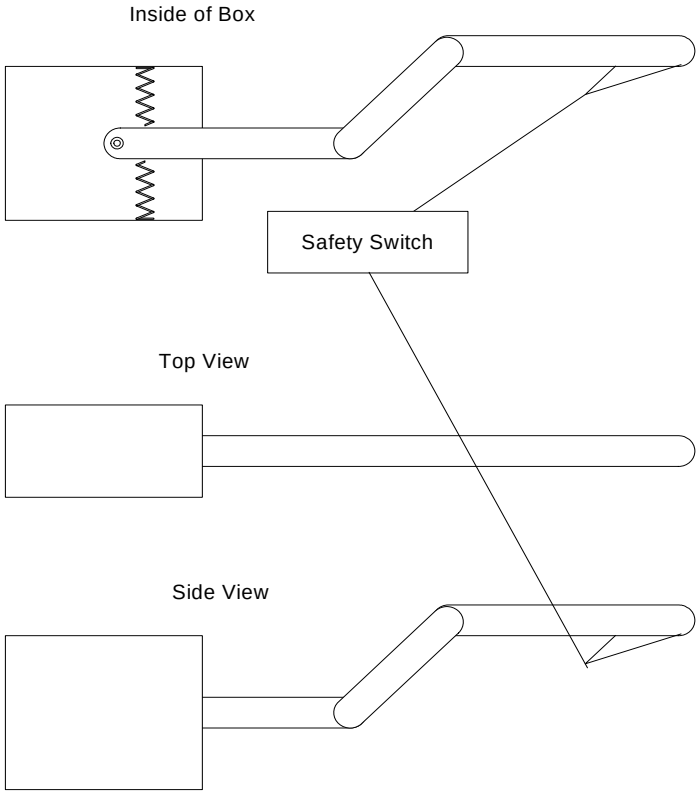


Figure 5: Basic Design of Handle

2.1.1.4 Hydraulic Control Valves

The hydraulic control valves are the physical control which the lever will be operating. In this system, two control valves are necessary in order to drive the bed both up and down at a controlled rate.

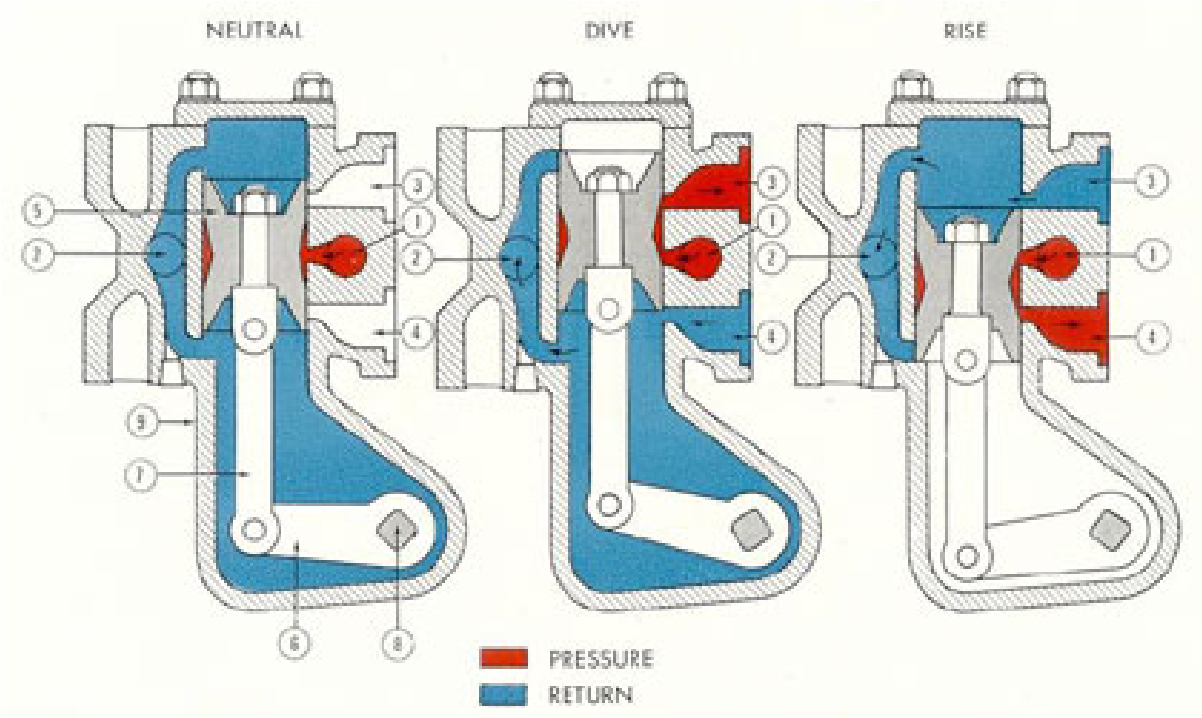


Figure 6: Control Valves [2]

(1) Input from pump (2) Outlet back to pump,
(3) To top of cylinder (4) To Bottom of cylinder

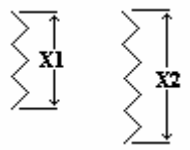
For use with a hydraulic cylinder, the valves will serve two functions, depending on the intended motion of the bed. The cylinder will have two hoses running in to it, one connected at either side of the driving piston (positions 1-4 in Fig. 6). When the lever is operated, it will open up one of the valves to allow the pressure from the pump into one side of the driving piston. At the same time, the other valve will be opened to allow fluid out of the cylinder. This open valve is connected to the end of the cylinder towards which the piston is traveling. The valves therefore function to create a lower pressure in front of the piston while the pump creates a higher pressure behind it, driving it in the opposite direction. By controlling the flow out of the piston with the valve, the pressure difference is regulated to drive the piston at the desired velocity.

2.1.1.5 Resistance Springs

The resistance springs are used in the control lever to bring the lever back to zero when the action is done, and to correlate an input force with an output displacement into the valves. To zero the lever, two springs with identical spring constants (k) will be attached between the lever, and opposite sides of the retaining box. The springs are to be sized such that both springs are stretched an equal amount when the lever is in the zero position. By stretching both springs even in at zero, makes both springs act equally on the lever at all times. Both

springs must also be stretched even when the lever is at its maximal displacement to both sides. This is required so that the shorter spring does not begin to compress and push back against the lever, making calibrations less precise.

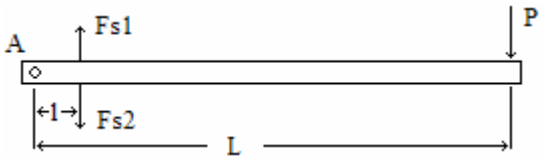
To design the proper control lever, the characteristics of the hydraulic piston-pump-valve system must be known. Once the relationship between the valve-lever displacement and the force output by the hydraulic cylinder is know, the input to output force can be calibrated. With a known hand displacement (Δx), and a known spring constant (k), force required to displace the spring-lever is equal to the spring constant times the displacement ($F=k\Delta x$) as shown in Figure 7.



($F=k\Delta x$; where $x_2-x_1=\Delta x$)

Figure 7: Calculation of Input Force on Springs

The force required to push at the end of the handle (P), can then be found by drawing a basic free body diagram of the lever with springs as shown in Figure 8, and describing the moment about point A. By solving for P, the force to displace the lever some amount (x) is directly proportional to the force applied.



Where:

Fs1=k(L1)
Fs2=k(L2)
P=input force
$\Sigma M_A = 0 = P*L+Fs2*l - Fs1*l$
P = l*(Fs1-Fs2) / L
P = l*k*(L1-L2) / L

Figure 8: Free Body Diagram of Lever

2.1.1.6 Hydraulic Pump/Motor

The hydraulic circuit that provides the lifting force to adjust the bed is powered by the hydraulic pump. A pump creates hydraulic energy by mechanical means. There are a variety of different kinds of pumps, but they share some common characteristics. In order for any pump to work, it must first draw the hydraulic fluid into the pumping chamber by creating a slight vacuum. This allows atmospheric pressure on the open reservoir tank to force the fluid into the pump. Once it is inside the pump, further mechanical operation forces the liquid out the other side, simultaneously drawing more in. One important factor to note is that the pump itself does not create pressure. It merely causes liquid to flow. Pressure is a result of the resistance to that flow that the pump creates, i.e., without a load, pressure at the outlet of the pump is always zero. This means that the pressure in the system will not rise past that which is required to overcome the load. Pumps are categorized as either positive-displacement or non-positive-displacement. Non-positive-displacement pumps are not sealed well internally. This allows some 'slippage' of fluid back thru the pump under high pressure. The significance of this is that the pump's output is reduced as pressure increases. On the other hand, positive-displacement pumps allow insignificant fluid slippage, if any at all, and are as efficient under high pressures as they are at lower pressures.

The pump attribute that is most important to the proposed design is its pressure rating. The pressure rating of a pump is the maximum hydraulic pressure that the pump can operate against. Since the weight of the patient on the bed will be acting on the hydraulic piston in a downward direction, it creates a pressure in the closed hydraulic circuit. Taking the cylinder's bore size and the hydraulic tubing's diameter into consideration, the pump must be able to exert a constant pressure on the system of around 200 psi in order to lift a patient that weighs 400 pounds. This is a relatively low pressure for hydraulics, since they are mainly used for heavy industrial work such as lifting cars or splitting logs. Because of this, most hydraulic pumps are designed to produce pressures of around 2000 psi, an order of magnitude higher. However, some commercial pumps designed for use in low pressure systems such as car washes can be used.

One such device is the PROCON series 4 pump (Fig. 9), which has a maximum pressure rating of 250 psi. This is approximately what is needed by this device. This pump is a rotary vane type, which is positive-displacement. This sturdy pump is made of brass and is designed to produce a flow rate of 115 to 330 gallons per hour at 250 psi.

Figure 9: PROCON Series 4 Pump [3]

2.1.1.7 Motor

The same manufacturer also produces an electric motor to power the pump. The model 48YZ Frame Motor (Fig. 10) is suited to this design. It operates at low horsepower, and high horsepower is not needed. Also, it is a clamp-on type motor, which the Series 4 pumps accept.

The displacement required from a hydraulic pump is calculated by the equation $V_p = \frac{(Q_m)(231)}{(n_p)(\eta_{vol.p})}$ where V_p is the displacement in in3 per revolution, Q_m is the flow rate in gallons per minute, n_p is the pump shaft speed in rpm, and $\eta_{vol.p}$ is the pump's volumetric efficiency [4].

Figure 10: 48YZ Frame Motor [3]

2.1.1.8 Hydraulic Tubing and Fixtures

This tubing and fixtures (Fig. 11) are designed to withstand high pressures (max 250psi) and ensure no leaks. It will be used to connect the pump to the cylinder to the container of vegetable oil to the control valves and pressure regulator. The tubing and fixtures are all compliant with the design because it calls for 1/2" diameter.

Figure 11: Hose Connectors (left) and Hydraulic Hosing (right) for 250 psi [5]

2.1.1.9 Pressure Valve

This is a very important feature to this hydraulic circuit design. In order to ensure safe operation, the system must not be overloaded in pressure. The PROCON pump featured in Figure 9, page 12, has an output pressure of 250 psi. After preliminary calculations, it was determined that about a maximum of 60 psi will be needed to lift the back of the bed; therefore the pressure in the system will not need to be much more. This is where the pressure valve in Figure 12, next page, comes into the design. It allows the user to set a safe working maximum pressure of say 80 psi. Then the handle or lever described earlier will operate the control valve from zero psi up to the maximum set pressure by this valve. Basically, the pressure valve acts as a safety feature to filter out high pressure so that the patient is not thrown upwards at high pressures.

Figure 12: Pressure Valve Regulator [5]

2.1.1.10 Pressure Gauge and Adapter

This feature is very much needed so that when the pressure valve is dialing down the pressure, one will know the exact pressure in the system. The adapter will fit the hosing at ½" diameter lever fittings.

Figure 13: Pressure Gauge and Adapter [5]

2.1.1.11 Hydraulic Lift

One of the main components of this automatic lift system is the hydraulic cylinder. It is imperative that this cylinder is compatible with the system. Most cylinders are made for industrial systems that can lift millions of pounds.

However, this design is much lighter, only about 180 pounds of lifting force is needed. There are many things to consider when choosing the correct cylinder such as the relationships between pressure, area, displacement volume, flow, speed, and the influence of inefficiencies.

The bore size of the cylinder determines the mechanical advantage because it determines the size of the area that the force is concentrated, as shown below.

Table 1: Bore Size effecting weight lifted by cylinder

BORE	FORCE FACTOR		STATIC FORCE [LB]										VOLUMETRIC DISPLACEMENT [FT³/IN STROKE]	
			@60psi		@80psi		@100psi		@200psi		@300psi			
	FORWARD	REVERSE											FORWARD	REVERSE
1 1/8	0.99	0.85	59.4	51	79.2	68	99	85	198	170	297	255	0.000575	0.000489
3 1/4	8.3	7.5	498	450	664	600	830	750	1660	1500	2490	2250	0.00480	0.00450
4	12.6	11.8	756	708	1008	944	1260	1180	2520	2360	3780	3540	0.00727	0.00682
6	28.3	25.9	1698	1554	2264	2072	2830	2590	5660	5180	8490	7770	0.0164	0.0150

It was determined that for this design a bore size of 2 is efficient. Shown below in Figure 14 is the Prince Double Acting Hydraulic Cylinder which has a bore size of 2, stroke length of 18 inches and a maximum pressure of 2500psi. The double acting feature allows for the piston to be forced equally in both directions.

Figure 14: Prince Double Acting Hydraulic Cylinder [5]

In Figure 15, next page, the Trunnion mounting style is diagramed. The mounting of this cylinder is important to the design because it stabilizes the cylinder throughout its motion and keeps a low profile when the piston is retracted. A pivot joint will also be considered where the cylinder attaches to the back of the bed so that it allows angular movement as the bed raises and lowers.

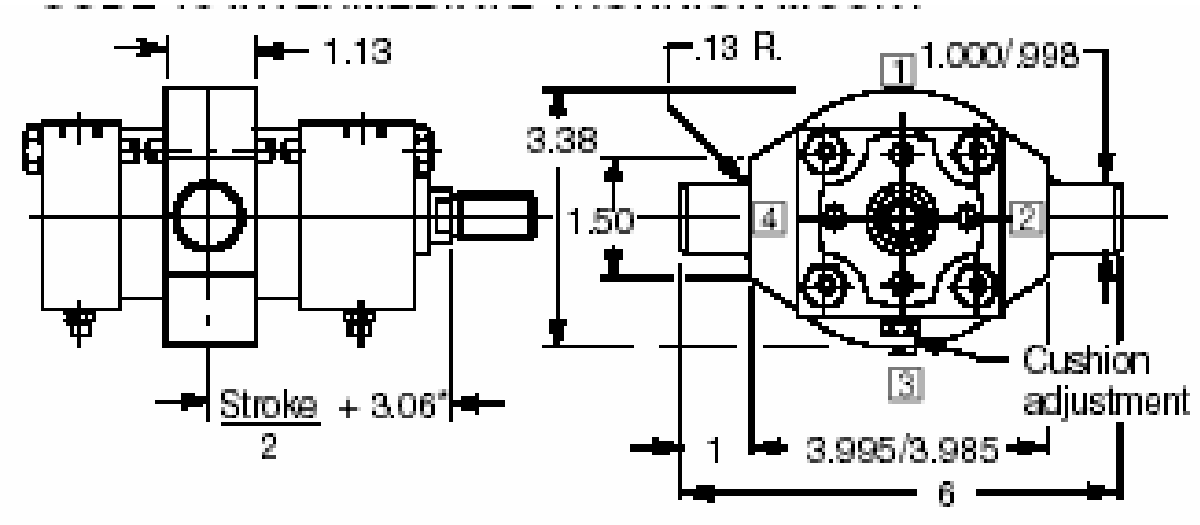


Figure 15: View of the Intermediate Trunnion Mounting Style

2.1.1.12 Polycarbonate Box

A box will be built out of a durable, clear Polycarbonate (Fig. 16) so that all the parts will be visible and contained underneath the bed neatly together without exposing any of the components. This should also make it easier to assemble the device since all the components are placed in the box. The only assembly needed would be the connection of hoses and stabilizing the position of the hydraulic lift on top of the box. It will hold the oil tank, motor and pump, hydraulic hosing connecting the components, and have a place where the user can see the pressure gauge and easily access the pressure regulator valve so that it can be adjusted as needed.

Figure 16: Clear Polycarbonate Sheets ¼" thick [5]

The overall schematic of the design is shown next page in Figure 17. It demonstrates the pivoting of the hydraulic cylinder to allow for movement as the bed is operated and sustains a low profile when retracted. Also, the handle is positioned out of the way and designed for easy access. All the remaining components are placed inside the polycarbonate box for protection and safety.

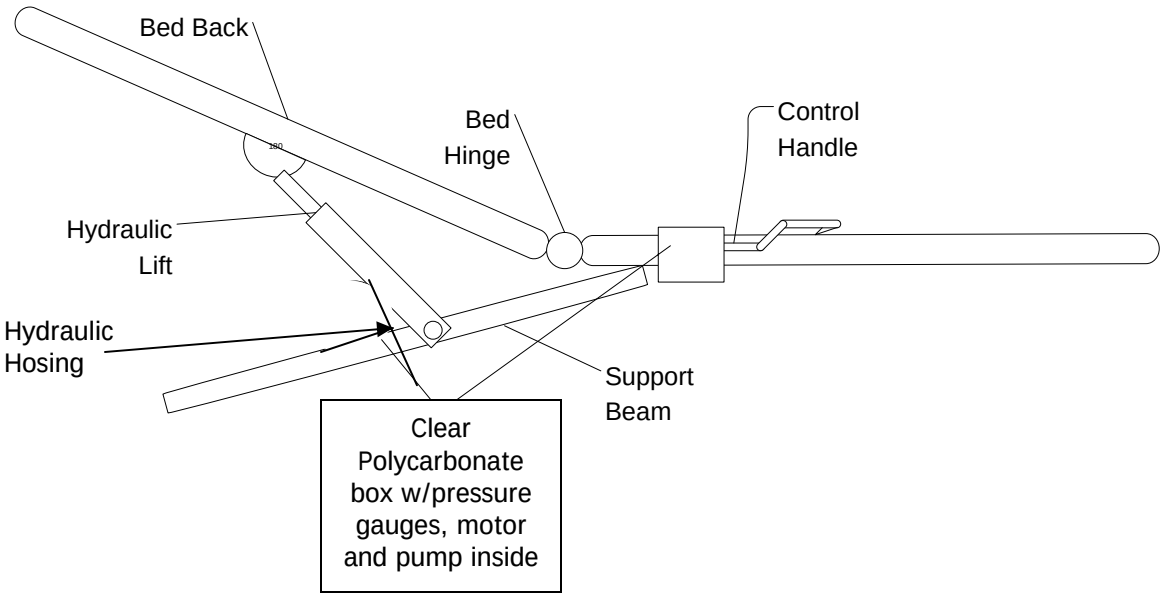


Figure 17: Overall design Schematic

14.1.2. Design 2

14.1.2.1. Objective

The objective of this design was to implement an electric system in place of the hydraulic system. Due to the potential for leaks in the hydraulic system, and the inherent noise generated by pumps, an electric system would be more suitable to a hospital and home setting. The action of the hydraulic piston is replaced by a single actuator which is driven by an electric motor. To control this motor, a rheostat is varied by the control handle rather than varying hydraulic valves. Potential problems will include the actuator length required, and the available torque from electric motors.

14.1.2.2. Control Lever

The control lever will consist of three main parts; a lever, a potentiometer, and two resistance springs. The lever will be approximately one foot long, and will be in the shape of a flattened "S". Figure 2 shows the preliminary shape which has been designed to keep the majority of the control lever below the surface of the bed, out of the way of both the patient and the care-giver, while still allowing easy access to the patient within the bed. The lever will be used to operate the potentiometer. The potentiometer will control the voltage supplied to the electric motor. When the lever is moved one way, the potentiometer will be varied so as to supply either a positive or negative voltage to the motor. If the

lever is moved in the other direction, the motor will be driven in the opposite direction. The electric motor will rotate one way or another depending on the sign of the voltage. With a greater amount of deflection on the lever, the potentiometer will increase the voltage to the motor, which in turn increases the speed of the motor. The resistance springs serve a two fold function. First of all, they will return the lever to its zero position, which will maintain zero voltage sent to the motor, causing the motor not to move, and to lock with the use of an electromagnetic brake. Second, the springs will provide the proper resistance so that a specific force will be required to displace the lever a specified amount. Therefore, the greater force applied to the lever, the greater voltage sent to the motor and a greater output speed to the bed back.

2.1.2.3. Lever

The lever will be the object moved by the user to operate the Adjustable Back Angle Controller. Its shape will be ergonomic, so as to make operation of the device as simple and comfortable as possible. One innovation is the "S" shape which has been incorporated in Figure 5, page 8.

This shape is designed to keep the majority of the control lever out of the way, but allow both the patient and caretaker to comfortably work the device. This should also help reduce the occurrences of the handle being bumped, since only a fraction of it will be above the protection of the bed mattress. Another feature is a safety lock, which will be built into the handle. In the occurrence of the lever being accidentally bumped, this safety switch will prevent the bed from operating. The safety switch (similar in appearance to a hand brake on a bicycle) will be a simple open loop switch. When the safety switch is on, the loop will be open. Since the input is conveyed to the motor via an electric circuit, any break in this will prevent the motor from being driven. The safety switch will be placed on the under side of the lever so that accidental activation does not occur in the event of force being applied from the top of the handle, such as the patient rolling over on the lever, or a visitor sitting on it. The safety switch will only require as little as one pound of force to unlock, so that all users will be able to operate it easily.

2.1.2.4. Resistance Spring

The resistance springs are used in the control lever to bring the lever back to zero when the action is done, and to correlate an input force with an output displacement into the valves. To zero the lever, two springs with identical spring constants (k) will be attached between the lever, and opposite sides of the retaining box. The springs are to be sized such that both springs are stretched an equal amount when the lever is in the zero position. By stretching both springs

even in at zero, makes both springs act equally on the lever at all times. Both springs must also be stretched even when the lever is at its maximal displacement to both sides. This is required so that the shorter spring does not begin to compress and push back against the lever, making calibrations less precise.

To design the proper control lever, the characteristics of the resistor circuit system must be known. Once the relationship between the resistance-lever displacement and the voltage output by the circuit is known, the input to output force can be calibrated. With a known hand displacement (Δx), and a known spring constant (k), force required to displace the spring-lever is equal to the spring constant times the displacement ($F=k\Delta x$) as shown in Figure 7, page 10. For example, if the maximum displacement of the springs is four inches and knowing that the maximum force applied is 20 lbs, it can be calculated that the spring constant needed is five.

The force required to push at the end of the handle (P), can then be found by drawing a basic free body diagram of the lever with springs as shown in Figure 8, page 10, and describing the moment about point A. By solving for P, the force to displace the lever some amount (x) is directly proportional to the force applied. To test the spring for the proper spring constant, the spring will be attached to an immobile surface. We will then measure its un-stretched length. A series of objects of known weight will then be hung from the spring, and the final stretched length of the spring will be measured. To solve for the spring constant (k), $F= k\Delta x$ can be rearranged to, $k = \frac{F}{\Delta x}$ where Δx is the change in length measured, and F is the weight of the object hung from it. After several repetitions, it will be possible to determine whether the spring truly does exert with a constant force to stretch ratio, or if the spring is defective, as well as validating the spring constant.

2.1.2.5. Electric Circuit

2.1.2.5.1. Overview

The electric circuit, in Figure 18, next page, serves to translate the mechanical action on the control handle into action of the linear actuator. Movement of the handle changes the relative voltages on either side of a potentiometer. The voltages are passed through separate inverting amplifiers, and are then compared by a differential amplifier. This final voltage is then applied to the motor on the linear actuator. The circuit will be designed and simulated in PSPICE. After the parts come in the circuit will be constructed on a protoboard and tested using a digital multimeter. Finally, the parts will be

soldered into a circuit board designed for this purpose and once again tested with a multimeter before being integrated with the rest of the device.

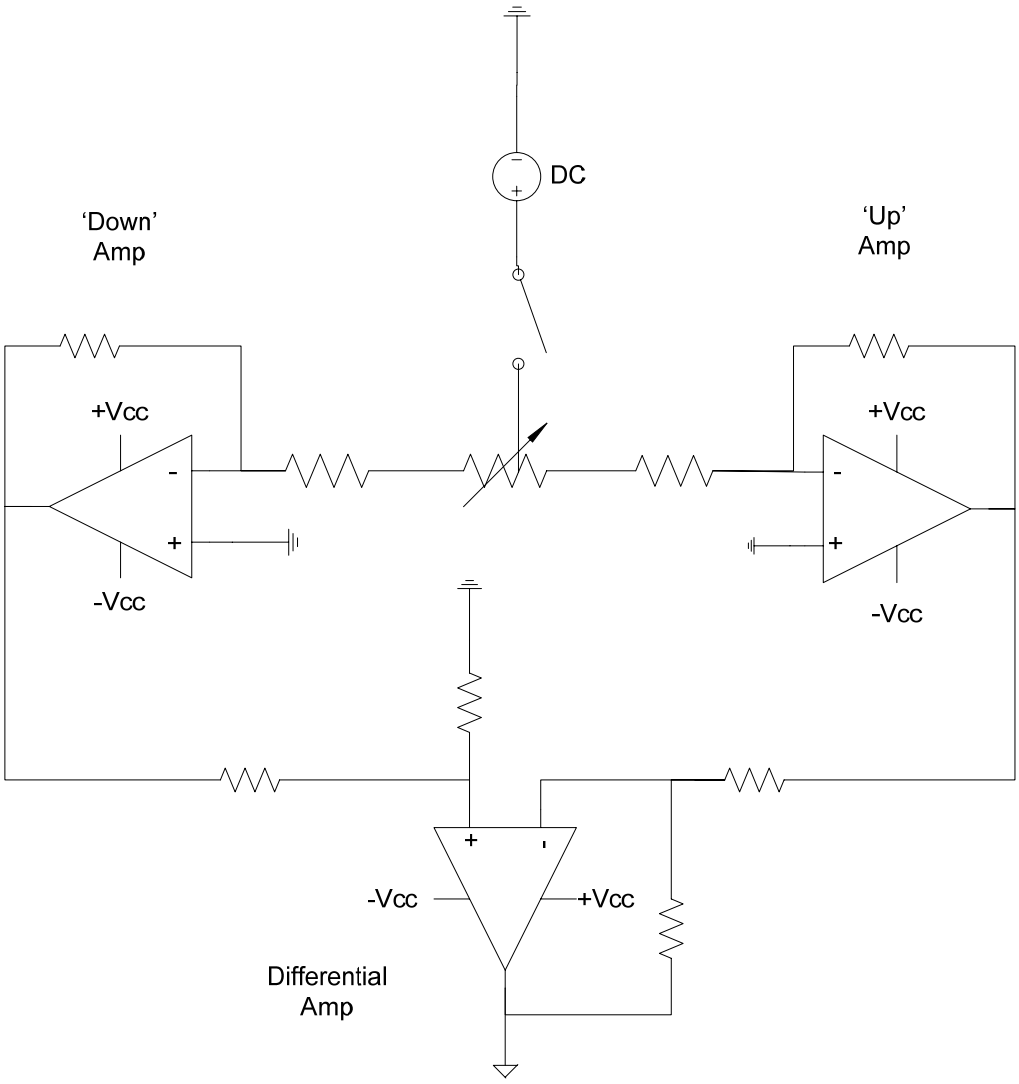


Figure 18: Circuit Schematic

2.1.2.5.2. Potentiometer

The potentiometer is directly attached to the handle. A potentiometer is a variable resistor that acts as an electro-mechanical transducer. This means that it converts mechanical stimuli into electric effects. The potentiometer will convert the displacement and direction of the handle into a variation of resistance within a circuit. A potentiometer has three terminals that can be connected to the rest of the electrical circuit. The resistance between the two end terminals is constant and is set at manufacturing. However, the resistance between the middle terminal and either terminal adjacent to it changes as the shaft is rotated. A typical potentiometer is pictured in Figure 19, next page.

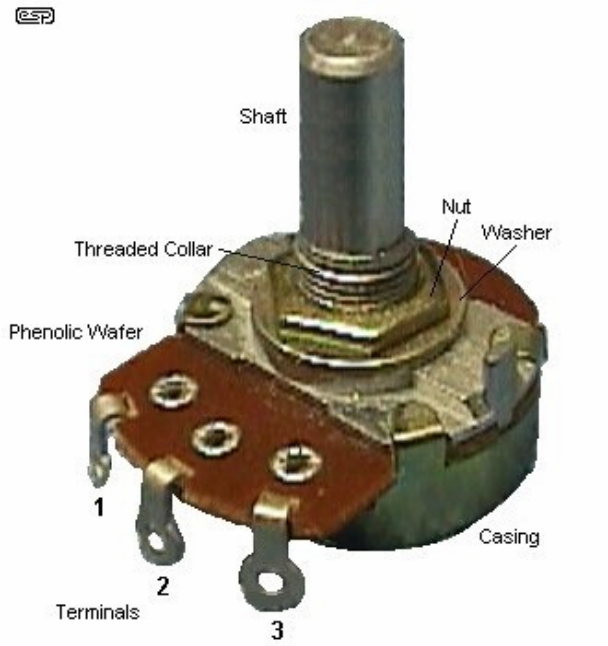


Figure 19: Typical Rotary Potentiometer [2]

Inside the potentiometer is a long resistor with its ends attached to either end terminal. The middle terminal is connected to a wiper that moves along the resistor. The resistance between the end terminal and the middle terminal varies according to how far the wiper is along the resistor. This is shown in Figure 20.

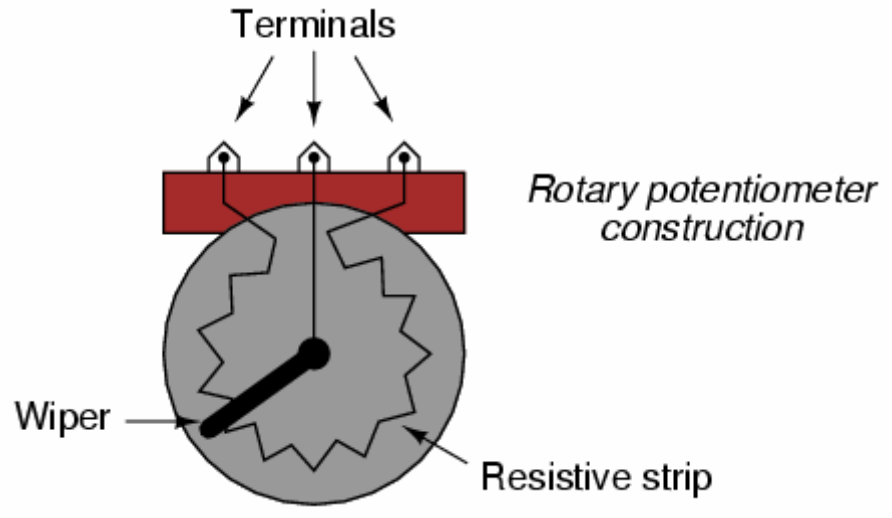


Figure 20: Internal Workings of Rotary Potentiometer [3]

In this design the DC power voltage will be applied to the center terminal. In this situation the voltage at either end terminal is related to the amount of internal resistor that is between the wiper and the terminal and the wiper and opposite terminal. For example, if the wiper is moved as far toward

the terminal as possible, the voltage at that terminal will be equal to the middle terminal. The opposite is also true. For this device the default position will be the center, where equal voltages will be output to both end terminals. When movement of the handle rotates the shaft and thus changes the position of the wiper, a voltage difference will appear at the two end terminals. When the lever is pushed downward, the potentiometer will be within the lower half of its range. The circuit will then output a negative voltage value, which will cause the motor to be driven in a direction which would lower the bed back angle. When the lever is raised, the potentiometer will be in the upper half of its range, causing the value sent to the motor to be positive, driving the motor in the direction corresponding to raising the bed back. These voltages will be amplified to control the actuator. In either case, greater displacement of the lever will produce a greater absolute value voltage output to the motor. This in turn will drive the motor at a faster rate.

2.1.2.5.3. Inverting Amplifiers

The voltage from each terminal is then sent to separate inverting amplifiers, of which operational amplifiers (op amps) are the central part. Op amps (such as the one shown in Fig. 21) are composed of resistors and transistors, all contained in a single IC chip.

Figure 21: Op Amp [4]

The resistors around the op amp will be configured with a resistor between the input voltage and the negative input (R_1) and with another between the output and the negative input (R_f). The positive input will be connected to ground. To simplify calculations, the op amps are assumed to be ideal. This means that they there is no input currents, and the input voltages are equal. In this scenario, the output voltage is $V_{out} = -(\frac{R_f}{R_1})V_{in}$ (see reference in Figure 22, next page) [5].By varying R_f and R_1, the output voltage can be amplified up to the op amp's control voltage. The inverting amps' main purpose in this circuit is to

amplify the voltage from the potentiometer terminals to a level that can be used by the motor.

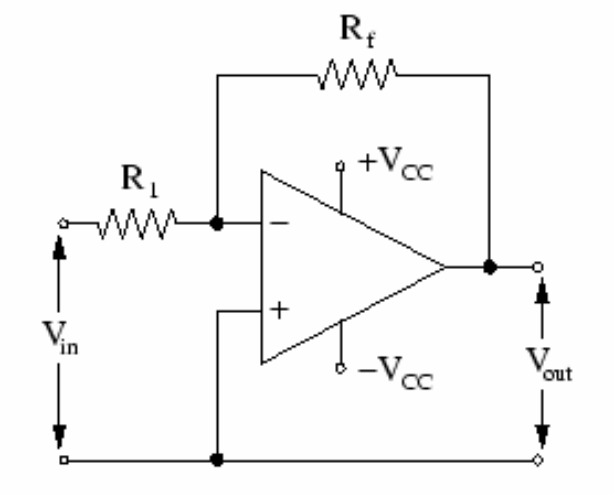


Figure 22: Inverting Amplifier Circuit [5]

2.1.2.5.4. Difference Amplifier

The two voltages from the inverting amplifiers are then both put into a single difference amplifier in Figure 23, next page. The difference amplifier also uses an op amp, but the supporting circuit is different. In addition to the resistors configured like those in the inverting amplifier, there is a resistor between the 2nd input voltage and the positive input (R_2) and another between the ground and the positive input (R_g). In this case all of the resistors will have the same value, which creates an expression for the output voltage $V_{out} = V_2 - V_1$ [5]. The inverting amp from the potentiometer terminal associated with raising the bed back up will be V_1 and connected to the negative input on the difference op amp. Since the inverting amplifier had made it negative, having a greater V_1 will cause the difference amplifier to output a positive voltage. This will cause the motor to drive the linear actuator up. When V_2 is higher (i.e., the bed back will be moved down), then the output voltage will be negative and the motor will retract the actuator.

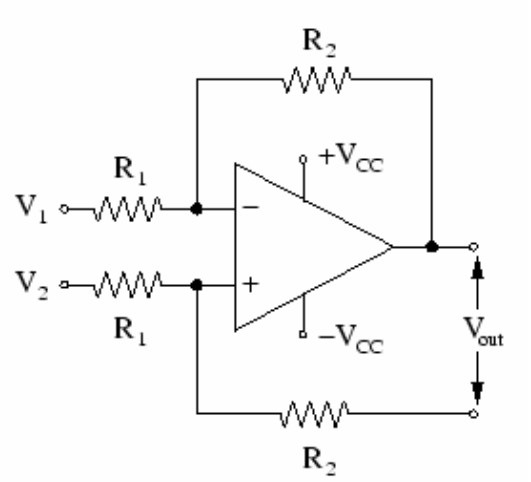


Figure 23: Differential Amplifier Circuit [5]

2.1.2.5.5. Filter

Between the difference amplifier and the motor will be a large resistor. This is to compensate for the fact that it will be difficult for the springs to center the potentiometer exactly. This will cause there to be a slight difference in voltage between the terminals, so there will be a small output voltage from the circuit. This resistor serves to prevent these small voltages from influencing the motor by effectively removing them.

2.1.2.6. Electric Motor

The electric motor used to drive the bed back up and down will be a variable speed series wound DC motor. In this motor, the stator and rotor are connected in series across the voltage source (see Figure 24, next page), producing equal operating current in both. By using a simple circuit (see Figure 18, page 20) to control the applied voltage, the DC voltage and speed of the motor can be controlled. As it was explained previously, the greater the voltage, the faster the motor runs causing the actuator rise or lower faster, and visa versa with less voltage. Depending on the polarity of the voltage, this will determine which way the rotor or armature rotates. Positive voltage will cause the rotor to rotate such that it drives the actuator up and raise the bed. Negative voltage will rotate the rotor in the opposite direction and cause the actuator to retract and lower the bed. The major drawback of this motor type is that if a "no load" condition occurs ("zero torque speed"), the motor could accelerate beyond its mechanical design limit and fail [6]. However, this will never happen in this device because there will always be some load on the system due to the weight of the bed back. In choosing a motor, it will have the appropriate rotations per minute (RPM) and be able to handle the voltage outputted by the circuit. This can be tested by supplying a range of DC power to the motor and measuring the

RPMs by hooking up a tachometer to verify its speed. For proper operation, the torque and horsepower need to be calculated and can be determined with Equation 1.

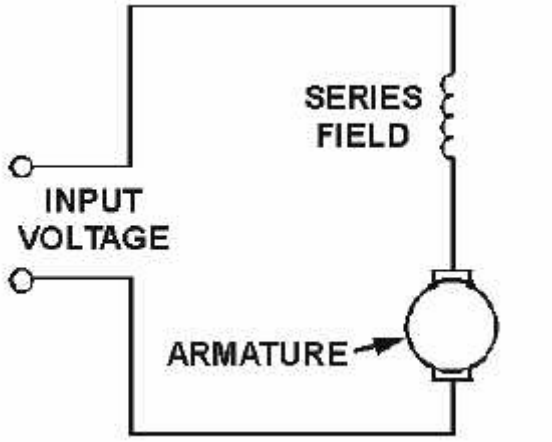


Figure 24: Circuit for a Series Wound DC Motor [7]

$$Power(hp) = \frac{torque(ft*lb)*angularspeed(rpm)}{5252} \qquad \text{Eq 1 [8]}$$

2.1.2.7. Actuator

The actuator converts the rotational motion of the electric motor into linear motion to drive the bed back, up and down. This is typically done through the use of a lead screw or worm gear drive. As shown in Figure 25, next page, the motor drives the lead screw in a circular motion. Due to the threading on the lead screw, and the load nut, this circular motion is transformed into linear motion as the load inches up the threading with each full rotation of the lead screw. The roles of the load nut and the lead screw can be reversed should the operation require it. In such a case, the motor would rotate a fixed threaded nut, in which the lead screw would sit. The load would then be placed at one end of the lead screw. As the nut is rotated by the motor, the lead screw will be forced through it, in one direction or the other, via the threading on each. This in turn would then drive the load upwards.

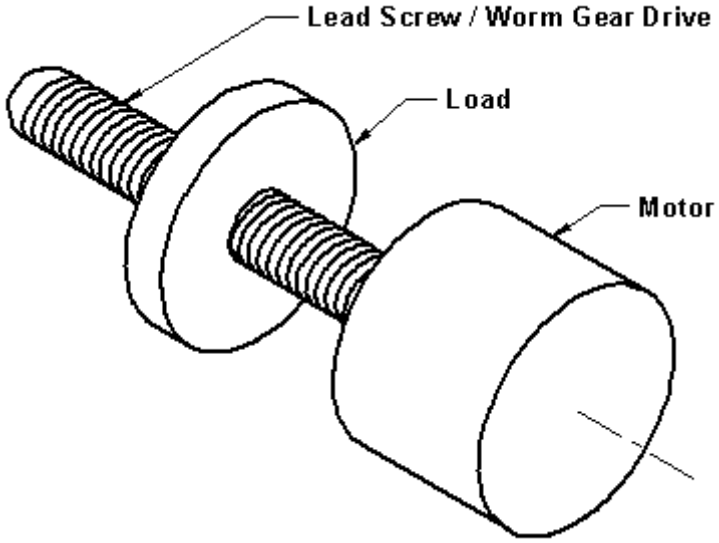


Figure 25: Worm Gear / Lead Screw Drive System [9]

The rate of linear motion performed by an actuator such as this is a function of the revolution speed of the motor, in revolutions per min (rpm), and the pitch of the thread, in inches per revolution (in/rev), as shown in Eq 2.

$$V = threadpitch * angularspeed \qquad \text{Eq 2}$$

With each turn of the nut, the lead screw will travel a distance equal to the pitch value of the thread. Therefore, the faster the motor spins, the faster the load is moved.

In this design, an actuator will be used to move a cart forward and backward along the length of the bed. A solid rod will then be attached between the cart and the bed back via a pin at the bed (upper pivot joint) and then cart (lower pivot joint), as shown on the following pages in figures 26 & 27. This pin will allow the rod to pivot at both ends as the cart traverses a track. As the cart travels toward the foot of the bed, the horizontal distance between the lower pivot joint and the upper pivot joint will be come shorter. Since the rod remains a constant length, this means that the vertical distance between the two joints must increase.

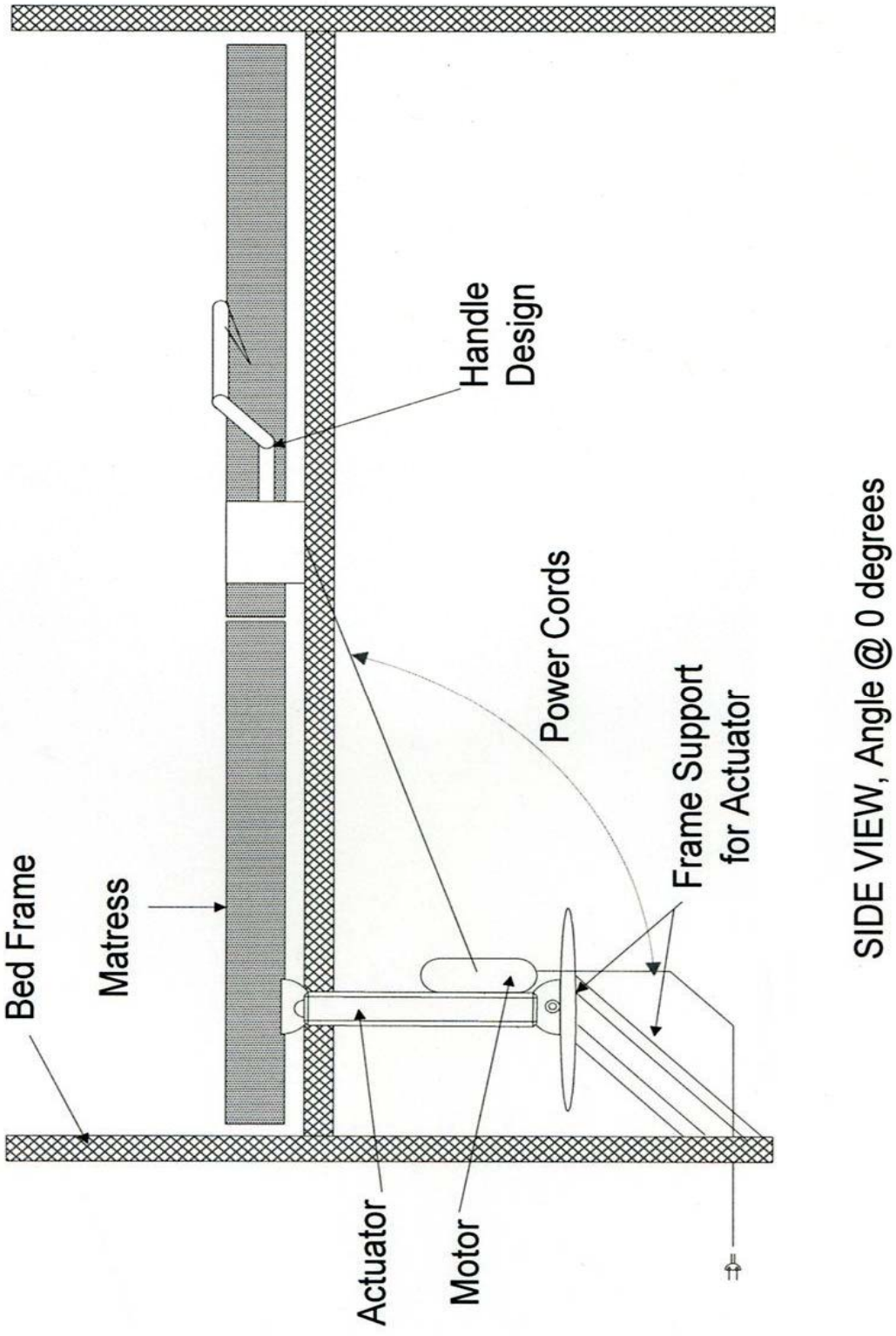


Figure 26: Overall Schematic at 0 Degree Angle

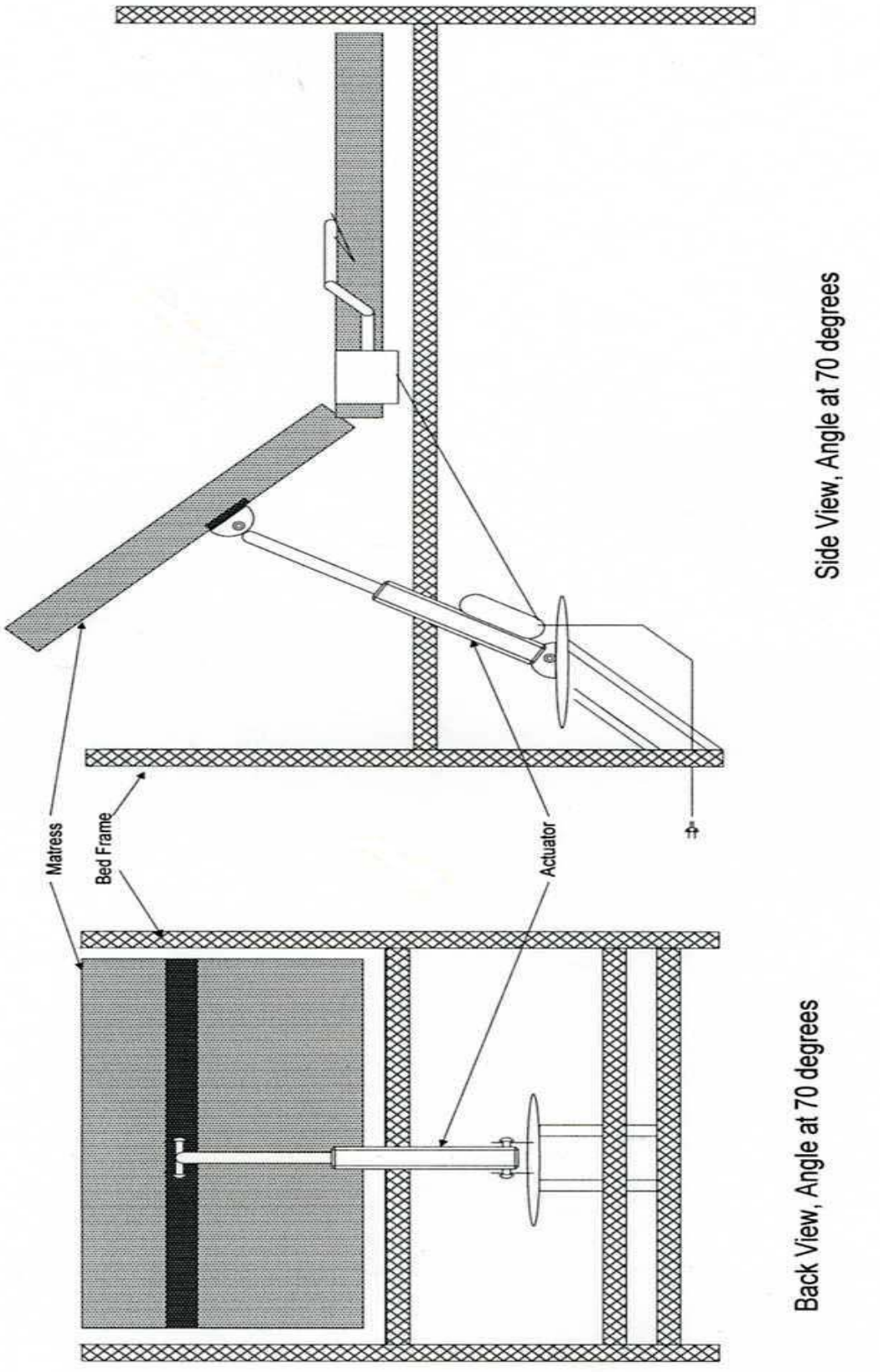


Figure 27: Overall Back and Side View of Schematic at 70 Degrees

To calculate the required materials for the actuator, the following free body diagram and equations are used.

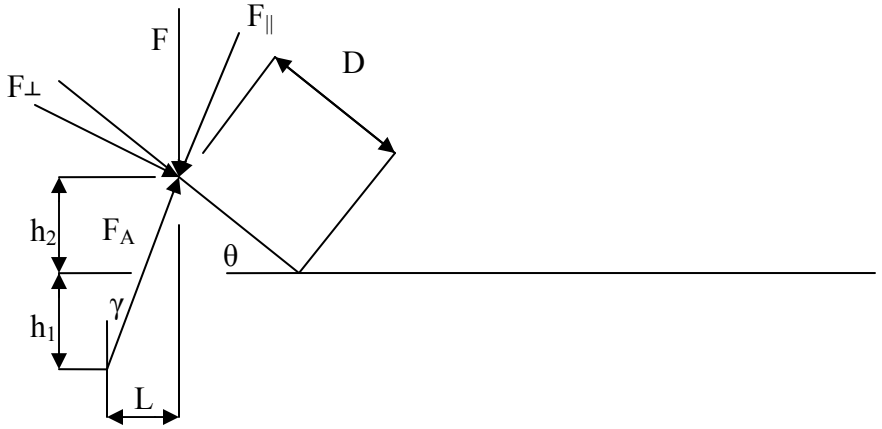


Figure 28: Free Body Diagram of Lifting System

Where:

F = Weight of Patient*0.45
h_2 = Raise in bed at θ degree incline (D*sin(θ))
h_1 = Length of Fully Retracted Actuator
θ = degree incline in bed back
D = Distance of connection point from bed joint
F_A = Force applied by actuator
γ = degree tilt of actuator at θ degree incline in bed back ($\tan^{-1}\left(\frac{L}{h_1+h_2}\right)$)
F⊥ = Component of patient's weight perpendicular to actuator
$F_{||}$ = Component of patient's weight parallel to actuator
L = horizontal displacement of connection point (D*cos(θ))
I = Area Moment of Inertia of Actuator Shaft ($\frac{\pi}{64}d^4$)
d = Diameter of Actuator Shaft
c = radius of Actuator Shaft
A = Cross-sectional Area of Actuator Shaft
T = Torque Output by Motor

Bending Moment on Actuator (in*lbs):

$$M = \frac{F_{||}}{A} = \frac{F * \cos(\gamma)}{A} \qquad \text{Eq. 3}$$

Stress due to Bending (psi):

$$\sigma_{bending} = \frac{M * c}{I} = \frac{F * L * \frac{d}{2}}{\frac{\pi * d^4}{64}} = \frac{10.19 * F * D\cos(\theta)}{d^3} \quad \text{Eq. 4}$$

Direct Shear Stress (psi):

$$\tau = \frac{F_{\perp}}{A} = \frac{F * \sin(\gamma)}{A} \quad \text{Eq. 5}$$

Shear Due to Torsion (psi):

$$\tau_{torque} = \frac{T * c}{J} = \frac{T * \frac{d}{2}}{2 * I} = \frac{T * \frac{d}{2}}{\frac{2 * \pi * d^4}{64}} = \frac{5.09 * T}{d^3} \quad \text{Eq. 6}$$

Assuming that the force from the patient's weight is focused at about 1/3 of the length of the bed back, 35 inches in length, from the joint we assume that F is concentrated at D=15 inches. Therefore, the actuator will also be placed at this point so that the majority of the weight is directly supported. The bed is also projected to lift from 0 degrees to 70 degrees of incline. Therefore, the actuator will be under the greatest tensile and shear stresses while at its maximum amount of incline. To determine the proper material and diameter for the actuator shaft, we assume the maximum load of 180 pounds is applied at the connection. Knowing the force applied at the joints, the proper mounting brackets must be used to compensate for movement of the actuator as its angled. The clevis bracket (Fig. 29) will be pinned to both ends of the actuator to provide a sturdy attachment and allow for pivoting as the bed back angle changes.

Figure 29: Linear Actuator Mounting Bracket [10]

2.1.2.8. Support Frame

After understanding all the loads that this device needs to withstand, a strong support frame for the actuator can be determined. The most practical metal to use in this situation is Aluminum-Beryllium (Al-Be) 80/20. This is a light weight, durable, easy to assemble, and cheaper way to structure this verse welding steel parts together. Below in Figure 30 is a picture of Al-Be 80/20 and chart of its mechanical properties. The design of this structure is seen in the overview of the frame in Figure 26 and 27, pages 27-28. This material will be ordered in the proper sizes and put together in the machine shop. Once the frame is finished, it will undergo a series of loading tests to test the strength of the structure. If failure is to occur, reinforcement will be added where necessary.

Nominal Density (lb./in3)	0.076 to 0.086
Yield (KSI)	23 to 40
Melting Point (°F)	2010 to 2150
Chemical Family	Metal matrix
Ultimate (KS)	34 to 55
Elongation (%)	17 to 7
Modulus (MSI)	19 to 28
Color	Gray

Figure 30: Properties of Aluminum-Beryllium 80/20 [11][12]

The overall schematic of the design (as illustrated in the Microsoft VISIO drawings in Figures 26 and 27, pages 27-28) demonstrates the pivoting of the actuator to allow for movement as the bed is operated and sustains a low profile when retracted. Also, the handle is positioned out of the way and designed for easy access. All parts are secured with bolts to the frame of the bed or the Aluminum. To demonstrate the final workings of this automatic back angle controller, it will be fastened to a mock bed platform. It can be made out of scrap Al-Be 80/20 or welded with steel and have a metal platform attached to mimic the mattress. This will allow the device to be tested under the weight of humans lying on the platform.

14.1.3. Design 3

14.1.3.1. Objective

Design 3 was a refinement of design 2. It retained the same force-sensitive handle idea from the previous design, which used springs to translate the physical force applied to the handle to displacement. Inside the joint of the handle was a rotary potentiometer that measured the rotation of the joint. However, the electric circuit controlling the motion of the bed was completely changed in order to ensure a large enough current for the motor. This circuit used pulse width modulation to control the speed of the DC motor and an H-bridge to control its direction.

Instead of a linear actuator, the motor turned a lead screw that was mounted underneath the bed parallel to the ground. Attached to the lead screw was a rigid bar that raised the bed back as the nut on the screw was forced backward. Rotating the screw in the opposite direction moved the nut forward, and thus lowered the bed back. The bed's frame was constructed out of 80/20 Aluminum/Beryllium.

14.1.3.2. Control Lever

The control lever will consist of three main parts; a lever, a potentiometer, and two resistance springs. The lever will be approximately one foot long, and will be in the shape of a flattened "S". Figure 2 shows the preliminary shape which has been designed to keep the majority of the control lever below the surface of the bed, out of the way of both the patient and the care-giver, while still allowing easy access to the patient within the bed. The lever will be used to operate the potentiometer. The potentiometer will control the voltage supplied to the electric motor. When the lever is moved one way, the potentiometer will be varied so as to supply either a positive or negative voltage to the motor. If the lever is moved in the other direction, the motor will be driven in the opposite direction. The electric motor will rotate one way or another depending on the sign of the voltage. With a greater amount of deflection on the lever, the potentiometer will increase the voltage to the motor, which in turn increases the speed of the motor. The resistance springs serve a two fold function. First of all, they will return the lever to its zero position, which will maintain zero voltage sent to the motor, causing the motor not to move, and to lock with the use of an electromagnetic brake. Second, the springs will provide the proper resistance so that a specific force will be required to displace the lever a specified amount. Therefore, the greater force applied to the lever, the greater voltage sent to the motor and a greater output speed to the bed back.

2.1.3.3. Lever

The lever will be the object moved by the user to operate the Adjustable Back Angle Controller. Its shape will be ergonomic, so as to make operation of the device as simple and comfortable as possible. One innovation is the "S" shape which has been incorporated in Figure 5, page 8.

This shape is designed to keep the majority of the control lever out of the way, but allow both the patient and caretaker to comfortably work the device. This should also help reduce the occurrences of the handle being bumped, since only a fraction of it will be above the protection of the bed mattress. Another feature is a safety lock, which will be built into the handle. In the occurrence of the lever being accidentally bumped, this safety switch will prevent the bed from operating. The safety switch (similar in appearance to a hand brake on a bicycle) will be a simple open loop switch. When the safety switch is on, the loop will be open. Since the input is conveyed to the motor via an electric circuit, any break in this will prevent the motor from being driven. The safety switch will be placed on the under side of the lever so that accidental activation does not occur in the event of force being applied from the top of the handle, such as the patient rolling over on the lever, or a visitor sitting on it. The safety switch will only require as little as one pound of force to unlock, so that all users will be able to operate it easily.

2.1.3.4. Resistance Spring

The resistance springs are used in the control lever to bring the lever back to zero when the action is done, and to correlate an input force with an output displacement into the valves. To zero the lever, two springs with identical spring constants (k) will be attached between the lever, and opposite sides of the retaining box. The springs are to be sized such that both springs are stretched an equal amount when the lever is in the zero position. By stretching both springs even in at zero, makes both springs act equally on the lever at all times. Both springs must also be stretched even when the lever is at its maximal displacement to both sides. This is required so that the shorter spring does not begin to compress and push back against the lever, making calibrations less precise.

To design the proper control lever, the characteristics of the resistor circuit system must be known. Once the relationship between the resistance-lever displacement and the voltage output by the circuit is known, the input to output force can be calibrated. With a known hand displacement (Δx), and a known spring constant (k), force required to displace the spring-lever is equal to the spring constant times the displacement ($F=k\Delta x$) as shown in Figure 7, page 10.

For example, if the maximum displacement of the springs is four inches and knowing that the maximum force applied is 20 lbs, it can be calculated that the spring constant needed is five.

The force required to push at the end of the handle (P), can then be found by drawing a basic free body diagram of the lever with springs as shown in Figure 8, page 10, and describing the moment about point A. By solving for P, the force to displace the lever some amount (x) is directly proportional to the force applied. To test the spring for the proper spring constant, the spring will be attached to an immobile surface. We will then measure its un-stretched length. A series of objects of known weight will then be hung from the spring, and the final stretched length of the spring will be measured. To solve for the spring constant (k), F= kΔx can be rearranged to, $k = \frac{F}{\Delta x}$ where Δx is the change in length measured, and F is the weight of the object hung from it. After several repetitions, it will be possible to determine whether the spring truly does exert with a constant force to stretch ratio, or if the spring is defective, as well as validating the spring constant.

2.1.3.5. Electric Circuit

2.1.3.5.1 Overview

The electric circuit serves to translate the mechanical action on the control handle into action of the linear actuator. The circuit for this design is shown in Figure 31, next page. Rather than varying the speed of the DC motor by changing the input voltage, the design uses pulse width modulation (PWM) to control the speed [2]. PWM translates the input voltage to a square wave that ranges from 0V to a maximum voltage determined by the surrounding circuit. The amount of time that the wave is at the maximum voltage is controlled by the input voltage. For example, a wave generated by a maximum input will spend the maximum length of time at the high voltage. The opposite is also true. The main advantage of a PWM controlled motor is that it saves power compared to changing the voltage with a resistor, which creates an excessive amount of heat under high current levels. The circuit will be constructed and tested in PSPICE before it is physically assembled. After construction it will be tested using a digital multimeter and oscilloscope.

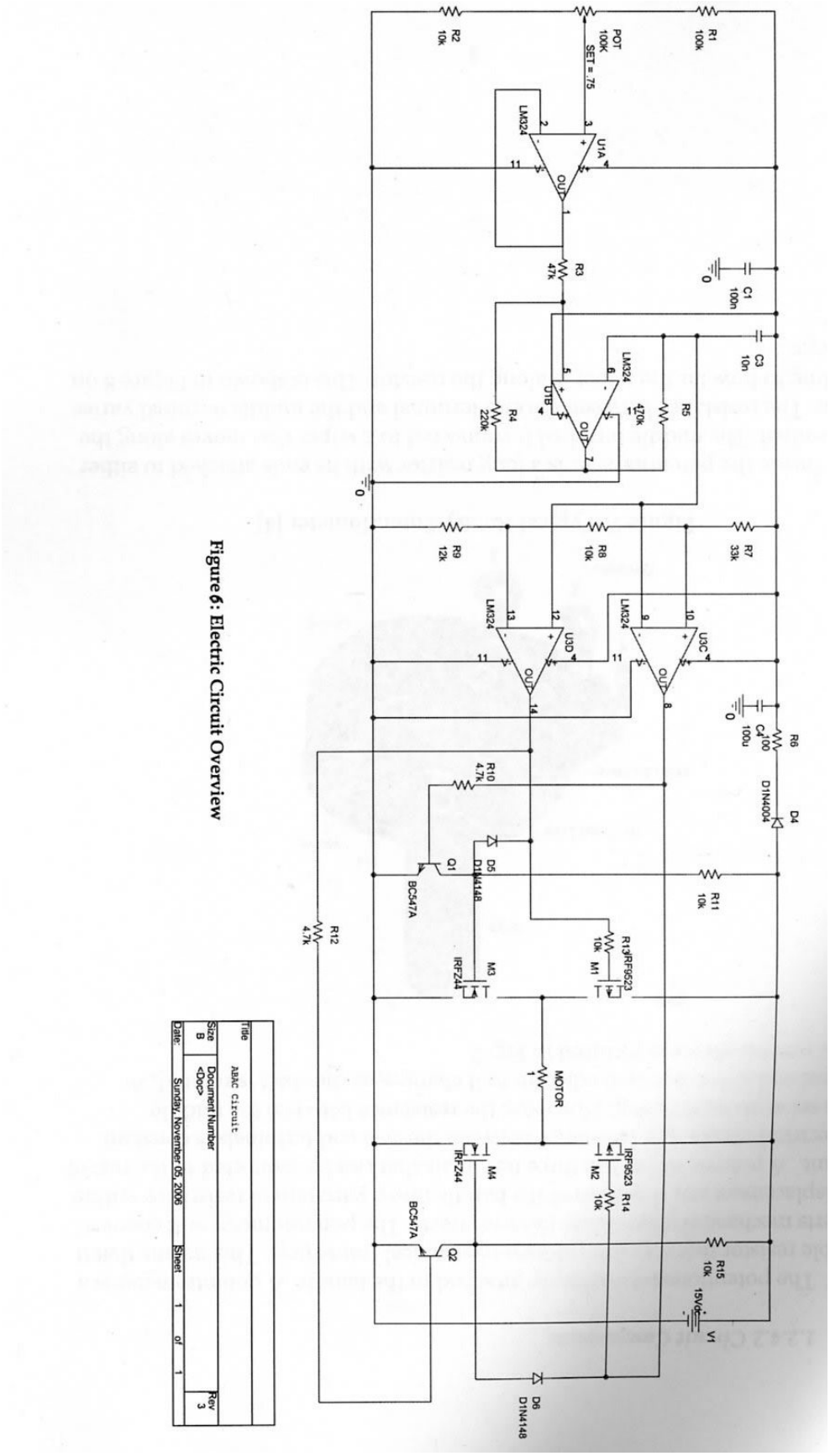


Figure 6: Electric Circuit Overview

2.1.3.5.2. Potentiometer

The potentiometer is directly attached to the handle. A potentiometer is a variable resistor that acts as an electro-mechanical transducer. This means that it converts mechanical stimuli into electric effects. The potentiometer will convert the displacement and direction of the handle into a variation of resistance within a circuit. A potentiometer has three terminals that can be connected to the rest of the electrical circuit. The resistance between the two end terminals is constant and is set at manufacturing. However, the resistance between the middle terminal and either terminal adjacent to it changes as the shaft is rotated. A typical potentiometer is pictured in Figure 19, page 21.

Inside the potentiometer is a long resistor with its ends attached to either end terminal. The middle terminal is connected to a wiper that moves along the resistor. The resistance between the end terminal and the middle terminal varies according to how far the wiper is along the resistor. This is shown in Figure 20, page 21.

The potentiometer is set up as a voltage divider circuit with middle pin connected to the non-inverting input of op amp U1A, which is an op amp configured as a voltage follower. Voltage followers have a gain very close to one and are used to safeguard the rest of the circuit from input extremes [5]. For this and all op amps in the circuit, the Vcc+ is supplied by the DC source, and Vcc- is ground. Optimally, all four op amps would be integrated into one IC chip, such as the LM324 quad op amp shown in Figure 32.

Figure 32: LM324 Quad Op Amp [6]

The output from the voltage follower is connected to the non-inverting input of U1B, which is a triangle wave generator. The triangle wave is generated from the charging and discharging cycles of the 10nF capacitor. This value and the resistance of R6 create a triangle wave with a frequency of around 270 Hz. The Amplitude of the wave is controlled by the voltage follower.

The triangle wave is output to two op amps (U1C and U1D) set in window comparator configuration. It is connected to the non-inverting input of U1D and the inverting input of U1C. U1C is turned on if the triangle wave input is higher than its non-inverting input. U1D is activated if the triangle wave is below its inverting input. The outputs from U1C and U1D are used to control four MOSFETs (Metal Oxide Semi-Conductor Field Effect Transistor) that direct the path of power from the DC source [7]. MOSFETs act like a voltage-controlled switch. If a voltage is applied to the gate pin, current is allowed to flow through the source and drain pins. Because the amplitude of the triangle wave cannot be more than the difference between the other inputs on the window comparator, both op amps cannot be on at the same time. This is important because if they both were on, the four MOSFETs would be activated at the same time, which would break them. A typical MOSFET is shown in Figure 33.

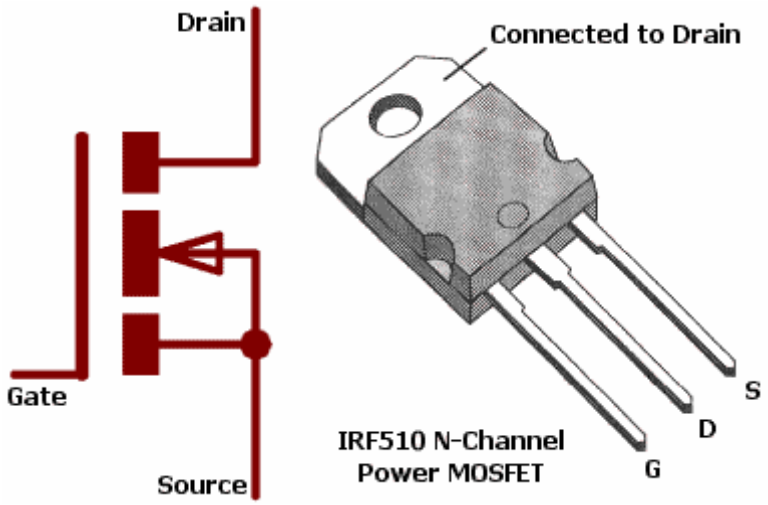


Figure 33: MOSFET [8]

Activating U1D causes a cascade of events that turns MOSFET Q3 on, JFET Q2 off, and MOSFET Q6 on. This allows power from the DC source to run through Q3, the motor, and Q6, causing the motor to turn in one direction. The length of time that power is allowed to the motor is controlled by the potentiometer input. Likewise, activating U1C turns Q4 on, Q1 off and finally Q5 on, completing a circuit from power through Q4, the motor, Q5, and then ground. This will cause the motor to turn in the opposite direction. As stated above, both U1C and U1D cannot be activated at the same time, which prevents all of the MOSFETs from being on simultaneously.

2.1.3.6. Electric Motor

The electric motor used to drive the bed, back up and down will be a variable speed series wound DC motor. In this motor, the stator and rotor are

connected in series across the voltage source (see Figure 24, page 25), producing equal operating current in both. This circuit (see Figure 31, page 34) design uses pulse width modulation (PWM) to control the speed of the motor. As it was explained previously, the greater the voltage, the faster the motor runs causing the actuator to rise or lower faster, and visa versa with less voltage. Depending on the polarity of the voltage, this will determine which way the rotor or armature rotates. Positive voltage will cause the rotor to rotate such that it drives the actuator up and raise the bed. Negative voltage will rotate the rotor in the opposite direction and cause the actuator to retract and lower the bed. The major drawback of this motor type is that if a "no load" condition occurs ("zero torque speed"), the motor could accelerate beyond its mechanical design limit and fail [9]. However, this will never happen in this device because there will always be some load on the system due to the weight of the bed back. In choosing a motor, an appropriate revolution speed, in rotations per minute (RPM), must be found and the motor must be able to handle the voltage outputted by the circuit. This can be tested by supplying a range of DC power to the motor and measuring the RPMs by the use of a tachometer to verify its speed. For proper operation, the torque and horsepower need to be calculated and can be determined with Equation 1.

$$Power(hp) = \frac{torque(ft * lb) * angularspeed(rpm)}{5252} \qquad \text{Eq 1 [11]}$$

2.1.3.7. Actuator

The actuator converts the rotational motion of the electric motor into linear motion to drive the bed back, up and down. This is typically done through the use of a lead screw or worm gear drive. As shown in Figure 25, page 26, the motor drives the lead screw in a circular motion. Due to the threading on the lead screw, and the load nut, this circular motion is transformed into linear motion as the load inches up the threading with each full rotation of the lead screw. The roles of the load nut and the lead screw can be reversed should the operation require it. In such a case, the motor would rotate a fixed threaded nut, in which the lead screw would sit. The load would then be placed at one end of the lead screw. As the nut is rotated by the motor, the lead screw will be forced through it, in one direction or the other, via the threading on each. This in turn would then drive the load upwards.

The rate of linear motion performed by an actuator such as this is a function of the revolution speed of the motor, in revolutions per min (rpm), and the pitch of the thread, in inches per revolution (in/rev), as shown in Eq 2.

$$V = threadpitch * angularspeed \qquad \text{Eq 2}$$

With each turn of the nut, the lead screw will travel a distance equal to the pitch value of the thread. Therefore, the faster the motor spins, the faster the load is moved.

In this design, an actuator will be used to move a cart forward and backward along the length of the bed. A solid rod will then be attached between the cart and the bed back via a pin at the bed (upper pivot joint) and then cart (lower pivot joint), as shown in Figures 34 & 35. This pin will allow the rod to pivot at both ends as the cart traverses a track. As the cart travels toward the foot of the bed, the horizontal distance between the lower pivot joint and the upper pivot joint will be come shorter. Since the rod remains a constant length, this means that the vertical distance between the two joints must increase.

To calculate the required materials for the actuator, the following free body diagram and equations are used.

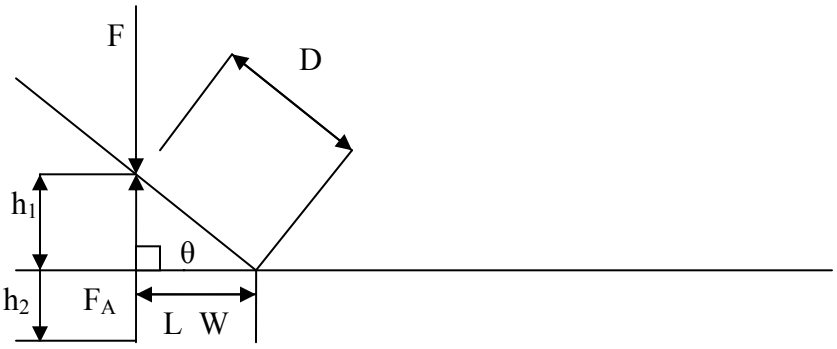


Figure 34: Free Body Diagram of Pin at 70°

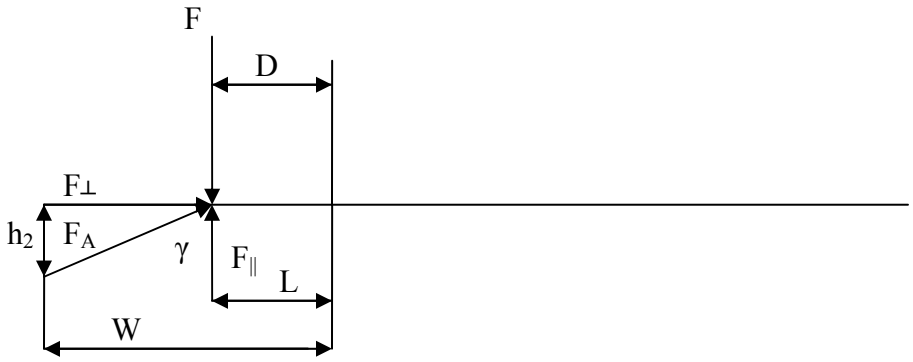


Figure 35: Free Body Diagram of Pin at 0°

Where:

θ – Raised Angle of the Bed Back

γ – Angle Between Support Rod and Vertical $\left(\frac{\cos^{-1}(D*\sin(\theta)+h_2)}{H}\right)$

D – Distance from Pivot Joint to Bed Joint (known)

W – Distance from Support Rod Lower Pivot Joint and Bed Joint

L – Horizontal Distance from Pivot Joint to Bed Joint (D*cos(θ))

H – Length of Support Rod (known)

h_1 – Height of bed Above Horizontal Position (D*sin(θ))

h_2 – Vertical Distance from Horizontal Bed and Lower Pivot Joint (known)

*F = 0.45*Weight of patient*

$F_{||} = F$

$F\perp = F_{||} * tan(\gamma)$

$$F_A = \frac{F}{\cos(\gamma)} = \frac{F}{\frac{\cos(\cos^{-1}(D*\sin(\theta)+h_2)}{H}} = \frac{F*H}{D*\sin(\theta)+h_2}$$

Direct Shear Stress (psi) (for pin)

$$\tau = \frac{F_A}{A} = \frac{F*\sin(\gamma)}{A} \qquad \textbf{Eq 3}$$

Stress due to Bending (psi) (for pin):

$$\sigma_{bending} = \frac{M*c}{I} = \frac{F_A * L * \frac{d}{2}}{\frac{\pi * d^4}{64}} = \frac{10.19 * F_A * D\cos(\theta)}{d^3} \qquad \textbf{Eq 4}$$

Assuming that the force from the patient's weight is focused at about 1/3 of the length of the bed back, 35 inches in length, from the joint we assume that F is concentrated at D=15 inches. It was determined that the rod and frame will be placed at this point so that the majority of the weight is directly supported. The bed is also projected to lift from 0 degrees to 70 degrees of incline. To determine the proper material and diameter for the rod shaft, it was assumed that the maximum load of 200 pounds is applied at the connection. Calculations show that the rod will be under the greatest tensile and shear stresses while at its initial incline at zero degrees. Table 2, next page, has the calculated forces on the rod that the screw drive will have to apply to drive the cart and Figure 36, next page, shows the forces graphically.

Table 2: Calculations of Force on Rod as Angle of Bed Changes

θ (degrees)	F_A (lb)	H (in)	D (in)	h_2 (in)	F (lb)	Travel (in)
0	669.8463	20.09539	15	6	200	28.7531869
5	550.0059					
10	467.0781					
15	406.6952					
20	361.0933					
25	325.7143					
30	297.7095					
35	275.2106					
40	256.9445					
45	242.0169					
50	229.7841					
55	219.7745					
60	211.6376					
65	205.1113					
70	200					

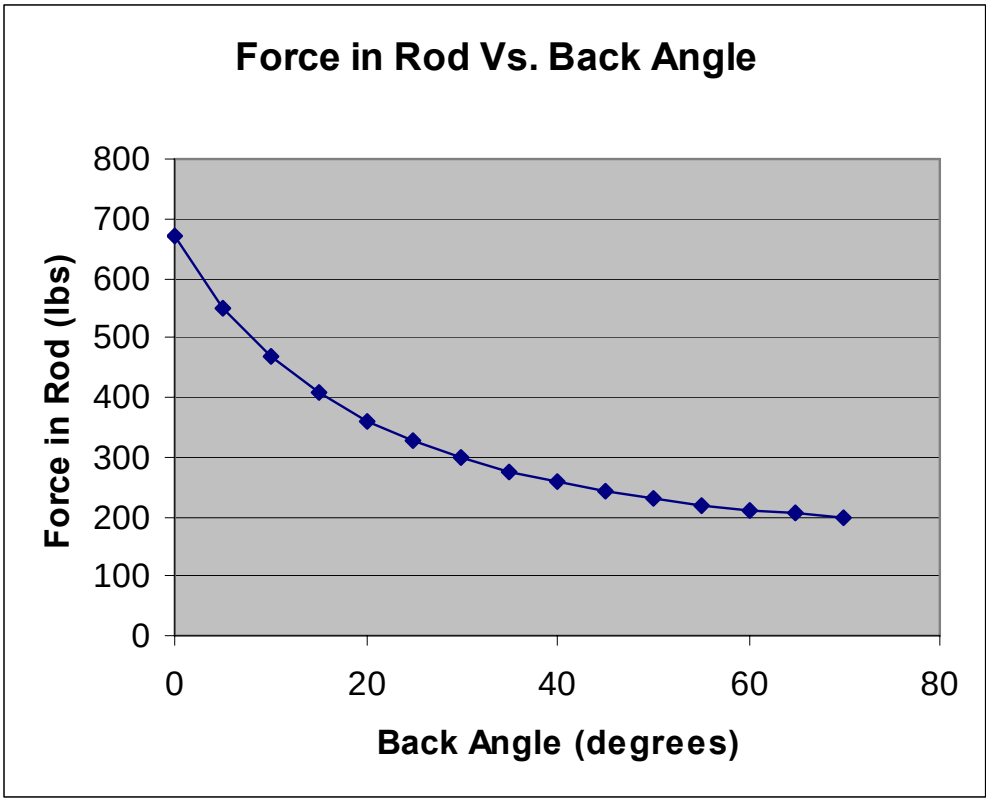


Figure 36: Graph of Force on Rod vs. Back Angle

Knowing the force applied at the joints, the proper mounting brackets must be used to compensate for movement of the rod as its angled. The clevis bracket (Fig. 29, page 30) will be pinned to both ends of the Al-Be 80/20 rod to

provide a sturdy attachment and allow for pivoting as the bed back angle changes.

2.1.3.8. Support Frame

After understanding all the loads that this device needs to withstand, a strong support frame for the actuator can be determined. The most practical metal to use in this situation is Aluminum-Beryllium (Al-Be) 80/20. This is a light weight, durable, easy to assemble, and cheaper way to construct this verse welding steel parts together. Figure 30, page 31, is a picture of Al-Be 80/20 and chart of its mechanical properties. The design of this structure is seen in the overview of the frame on the following pages in Figure 37 and 38. This material will be ordered in the proper sizes and put together in the machine shop. Once the frame is finished, it will undergo a series of loading tests to test the strength of the structure. If failure is to occur, reinforcement will be added where necessary.

The overall schematic of the design (as illustrated in the Microsoft VISIO drawings in Figures 37 and 38) demonstrates the pivoting of the actuator to allow for movement as the bed is operated and sustains a low profile when retracted. Also, the handle is positioned out of the way and designed for easy access. All parts are secured with bolts to the frame of the bed or the Aluminum. To demonstrate the final workings of this automatic back angle controller, it will be fastened to a mock bed platform. It can be made out of scrap Al-Be 80/20 or welded with steel and have a metal platform attached to mimic the mattress. This will allow the device to be tested under the weight of humans lying on the platform.

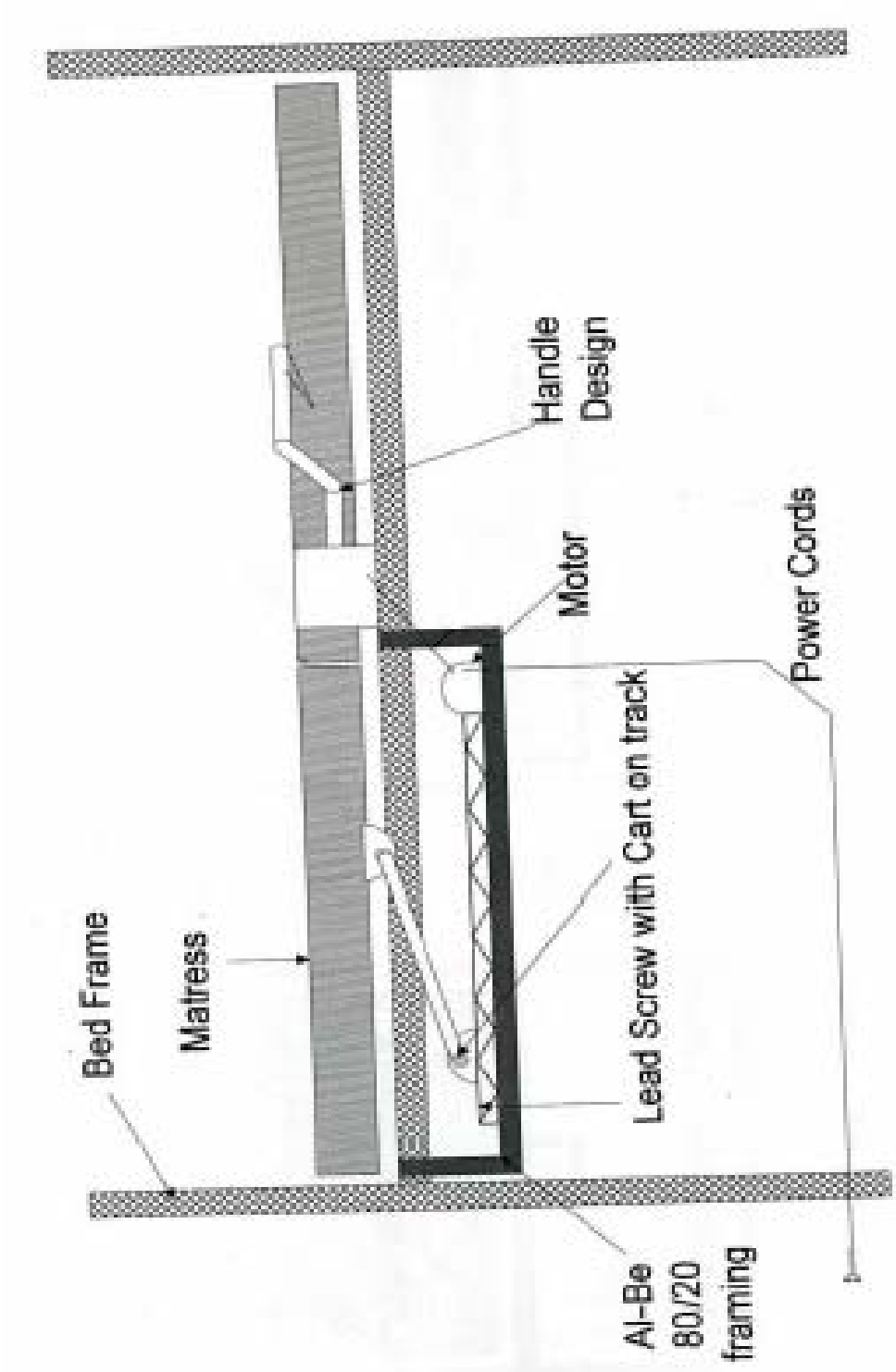


Figure 37: Overall Schematic at 0 Degree Angle for Design 3

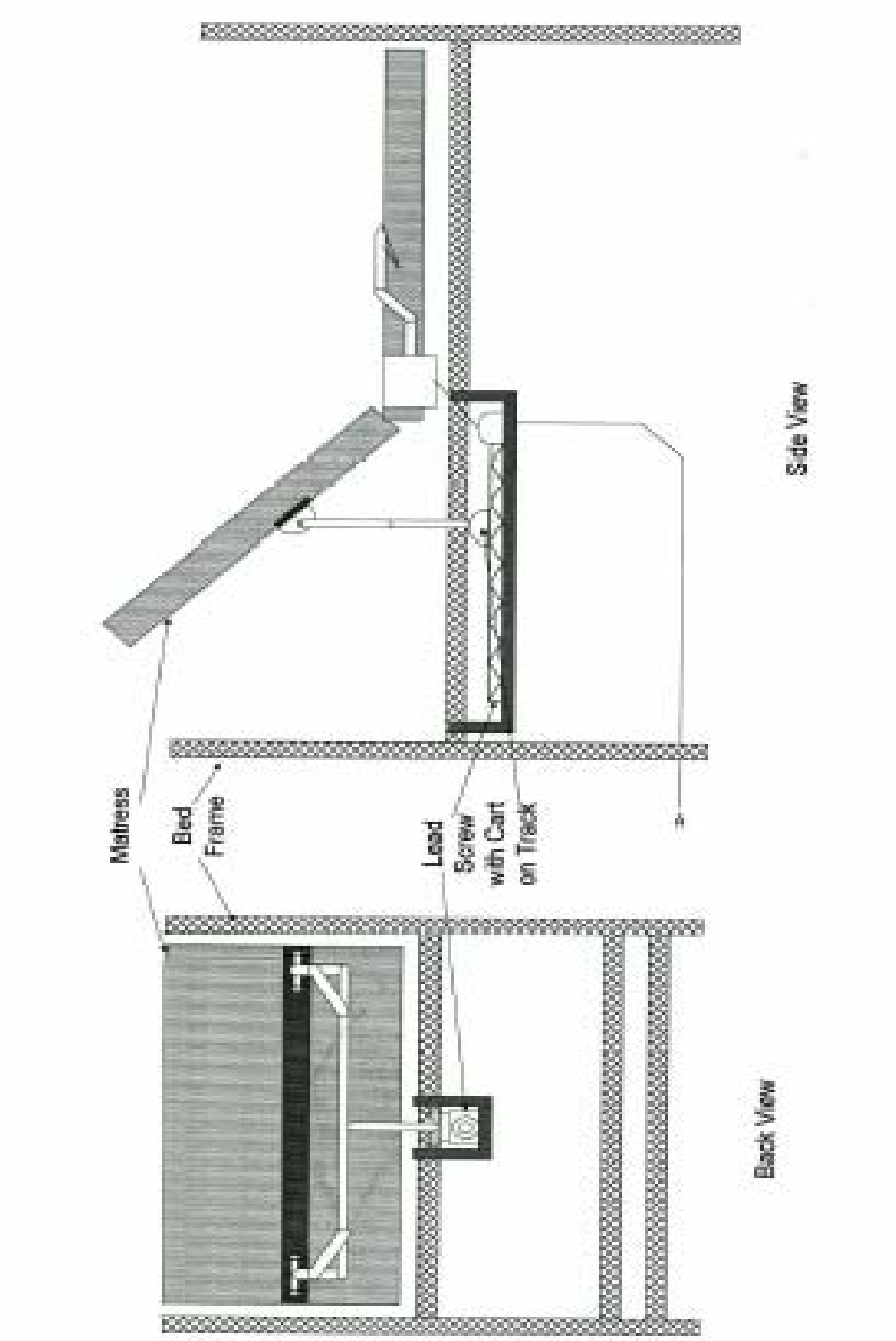


Figure 38: Overall Back and Side View of Schematic at 70 Degrees for Design 3

14.2. Optimal Design

14.2.1. Objective

The adjustable back angle controller must be easily accessible to the user to adjust the back angle of a bed. Rather than fumbling with a hand held remote to adjust the bed, the user will be able to pull on a handle and lift the bed back and patient. The care giver and patient will be able to apply a small force to the handle, and then that force will be multiplied to allow someone who can only lift 5 pounds to be able to adjust the bed of someone weighing 400 pounds. The movement of the bed back will be natural so that when a larger force is applied to the handle, the bed will incline at a faster rate and visa versa. This device will be applicable for patients of up to 400 pounds, assuming that 180 pounds or 45% of the person's total weight will be concentrated on the elevating portion of the bed. The handle will require an input range of 1 to 20 pounds. The input force can be applied to the system either mechanically or electrically. Mechanically, the handle will directly adjust a hydraulic flow control which will alter the pressure in the closed system and therefore drive the piston with a varying force. The electrical system consists of some type of variable resistor (i.e. Rheostat, Potentiometer, or strain gauge) that measures displacement of the handle by the change in resistance. With knowledge about the materials, and the measurement from variable resistance, a circuit will be designed to adjust a hydraulic flow control accordingly. Both methods would use a spring loading system to gauge the input force.

14.2.2. Subunits

14.2.2.1. Control Lever

The control lever will consist of three main parts; a lever with a safety switch, a potentiometer connected to a circuit, and two resistance springs. The lever will be approximately one foot long, and will be in the shape of a flattened "S". Figure 39, next page, shows the preliminary shape which has been designed to keep the majority of the control lever below the surface of the bed, out of the way of both the patient and the care-giver, while still allowing easy access to the patient within the bed. The lever will be used to change the resistance of the potentiometer. The potentiometer will control circuit which will adjust the average voltage supplied to the electric motor. When the lever is pulled up, the potentiometer will vary the circuit to supply a positive voltage to the motor. This will then raise the back of the bed up. The opposite will occur when the lever is pressed down. The electric motor will rotate depending on the sign of the voltage. With a greater amount of deflection on the lever, the potentiometer will

increase the voltage to the motor, which in turn increases the speed of the motor. The resistance springs serve a two fold function. First of all, they will return the lever to its zero position, which will maintain zero voltage sent to the motor, causing the motor not to move, and to lock with the use of an electromagnetic brake. Second, the springs will provide the proper resistance so that a specific force will be required to displace the lever a specified amount. Therefore, the greater force applied to the lever, the greater voltage sent to the motor and a greater output speed to the bed back.

2.2.2.2 Lever

The lever will be the object moved by the user to operate the Adjustable Back Angle Controller. Its shape will be ergonomic, so as to make operation of the device as simple and comfortable as possible. One innovation is the "S" shape which has been incorporated in Figure 39.

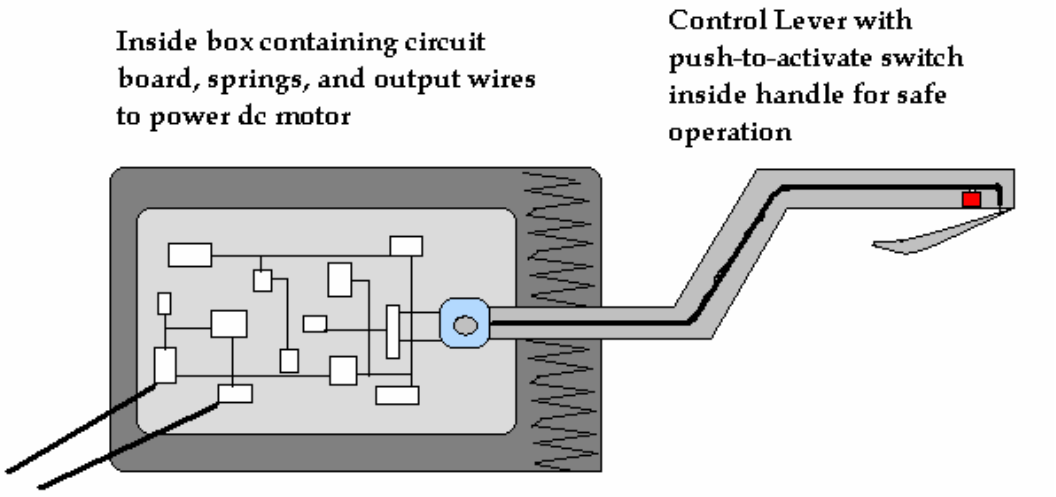

Inside box containing circuit board, springs, and output wires to power dc motor
Control Lever with push-to-activate switch inside handle for safe operation

Figure 39: Basic Inside Design of Handle

This shape is designed to keep the majority of the control lever out of the way, but allow both the patient and caretaker to comfortably work the device. This should also help reduce the occurrences of the handle being bumped, since only a fraction of it will be above the protection of the bed mattress. Another feature is a safety lock, which will be built into the handle. In the occurrence of the lever being accidentally bumped, this safety switch will prevent the bed from operating. The safety switch (similar in appearance to a hand brake on a bicycle) will be a simple open loop switch. The easiest way to implement this switch is to use a push-to make switch (Fig. 40, next page). A push-to-make switch returns to its normally open (off) position when you release the button; since the input is conveyed to the motor via an electric circuit, any break in this will prevent the

motor from being driven. The safety switch will be placed on the under side of the lever so that accidental activation does not occur in the event of force being applied from the top of the handle, such as the patient rolling over on the lever, or a visitor sitting on it. The safety switch will only require as little as one pound of force to unlock, so that all users will be able to operate it easily.

Figure 40: Push-to-Make Switch and Bracket Representation [2]

2.2.2.3 Resistance Springs

The resistance springs are used in the control lever to bring the lever back to zero when the action is done, and to correlate an input force with an output displacement into the valves. To zero the lever, two springs with varying spring constants (k) will be attached between the lever, and opposite sides of the retaining box. The springs are to be sized such that both springs are stretched an equal amount when the lever is in the zero position. By stretching both springs even in at zero, makes both springs act equally on the lever at all times. Both springs must also be stretched even when the lever is at its maximal displacement to both sides. This is required so that the shorter spring does not begin to compress and push back against the lever, making calibrations less precise.

To design the proper control lever, the characteristics of the resistor circuit system must be known. With a known spring displacement (Δx), and a known spring constant (k), the force required to displace the spring-lever is equal to the spring constant times the displacement ($F=k\Delta x$) as shown in Figure 7, page 10. For example, if the maximum displacement of the springs is one inch and knowing that the maximum force applied down is 20 lbs plus a small amount of weight from the handle, it can be calculated that the spring constant under the handle needed is just over twenty. This process may be more of a trial and error when it comes time to assemble.

The force required to push at the end of the handle (P), can then be found by drawing a basic free body diagram of the lever with springs as shown in Figure 8, page 10, and describing the moment about point A. By solving for P, the force to displace the lever some amount (x) is directly proportional to the force applied. To test the spring for the proper spring constant, the spring will be attached to an immobile surface. We will then measure its un-stretched

length. A series of objects of known weight will then be hung from the spring, and the final stretched length of the spring will be measured. To solve for the spring constant (k), F= kΔx can be rearranged to, $k = \frac{F}{\Delta x}$ where Δx is the change in length measured, and F is the weight of the object hung from it. After several repetitions, it will be possible to determine whether the spring truly does exert with a constant force to stretch ratio, or if the spring is defective, as well as validating the spring constant.

2.2.2.4. Electric Circuit

2.2.2.4.1. Overview

The electric circuit serves to translate the mechanical action on the control handle into action of the linear actuator. The circuit for this design is shown in Figure 31, page 34. Rather than varying the speed of the DC motor by changing the input voltage, the design uses pulse width modulation (PWM) to control the speed [3]. PWM translates the input voltage to a square wave that ranges from 0V to a maximum voltage determined by the surrounding circuit. The amount of time that the wave is at the maximum voltage is controlled by the input voltage. For example, a wave generated by a maximum input will spend the maximum length of time at the high voltage. The opposite is also true. The main advantage of a PWM controlled motor is that it saves power compared to changing the voltage with a resistor, which creates an excessive amount of heat under high current levels.

2.2.2.4.2. Circuit Components

The potentiometer is directly attached to the handle. A potentiometer is a variable resistor that acts as an electro-mechanical transducer. This means that it converts mechanical stimuli into electric effects. The potentiometer will convert the displacement and direction of the handle into a variation of resistance within a circuit. A potentiometer has three terminals that can be connected to the rest of the electrical circuit. The resistance between the two end terminals is constant and is set at manufacturing. However, the resistance between the middle terminal and either terminal adjacent to it changes as the shaft is rotated. A typical potentiometer is pictured in Figure 19, page 21.

Inside the potentiometer is a long resistor with its ends attached to either end terminal. The middle terminal is connected to a wiper that moves along the resistor. The resistance between the end terminal and the middle terminal varies according to how far the wiper is along the resistor. This is shown in Figure 20, page 21.

The potentiometer is set up as a voltage divider circuit with middle pin connected to the non-inverting input of op amp U1A, which is an op amp configured as a voltage follower. Voltage followers have a gain very close to one and are used to safeguard the rest of the circuit from input extremes [6]. For this and all op amps in the circuit, the Vcc+ is supplied by the DC source, and Vcc- is ground. Optimally, all four op amps would be integrated into one IC chip, such as the LM324 quad op amp shown in Figure 32, page 36.

The output from the voltage follower is connected to the non-inverting input of U1B, which is a triangle wave generator. The triangle wave is generated from the charging and discharging cycles of the 10nF capacitor. This value and the resistance of R6 create a triangle wave with a frequency of around 270 Hz. The Amplitude of the wave is controlled by the voltage follower.

The triangle wave is output to two op amps (U1C and U1D) set in window comparator configuration. It is connected to the non-inverting input of U1D and the inverting input of U1C. U1C is turned on if the triangle wave input is higher than its non-inverting input. U1D is activated if the triangle wave is below its inverting input. The outputs from U1C and U1D are used to control four MOSFETs (Metal Oxide Semi-Conductor Field Effect Transistor) that direct the path of power from the DC source [8]. MOSFETs act like a voltage-controlled switch. If a voltage is applied to the gate pin, current is allowed to flow through the source and drain pins. Because the amplitude of the triangle wave cannot be more than the difference between the other inputs on the window comparator, both op amps cannot be on at the same time. This is important because if they both were on, the four MOSFETs would be activated at the same time, which would break them. A typical MOSFET is shown in Figure 33, page 37.

Activating U1D causes a cascade of events that turns MOSFET Q3 on, JFET Q2 off, and MOSFET Q6 on. This allows power from the DC source to run through Q3, the motor, and Q6, causing the motor to turn in one direction. The length of time that power is allowed to the motor is controlled by the potentiometer input. Likewise, activating U1C turns Q4 on, Q1 off and finally Q5 on, completing a circuit from power through Q4, the motor, Q5, and then ground. This will cause the motor to turn in the opposite direction. As stated above, both U1C and U1D cannot be activated at the same time, which prevents all of the MOSFETs from being on simultaneously.

The circuit has been built and tested in PSPICE. After setting the simulation profile to transient, setting the time range, and raising the number of iterations, voltage markers were placed. One was put on the triangle wave generator output, one on the other input to comparator U1D, and one on it s

output. Figure 41 is the resulting graph, showing the triangle wave in green, reference voltage in yellow, and comparator output in blue. Whenever the triangle wave is higher than the reference voltage, the output is high.

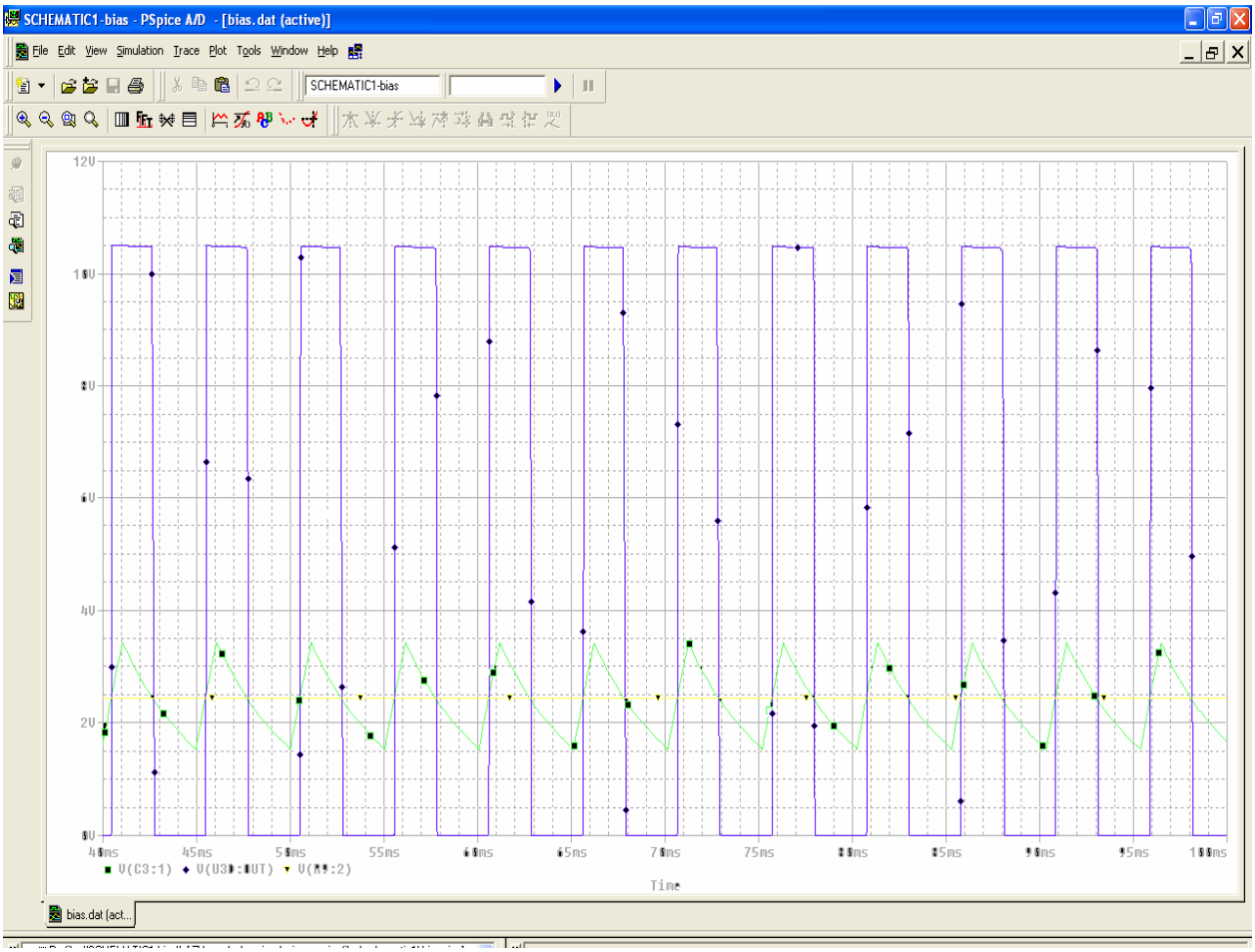


Figure 41 : PSPICE Simulation of Comparator Output

Once the control half of the circuit was confirmed to be working as planned, current markers were placed on the drains of MOSFETs M1 and M3 to confirm that they are switching properly. Figure 42, next page, shows that they are, with M3 staying closed the entire time and M1 opening and closing in response to the comparator's PWM input.

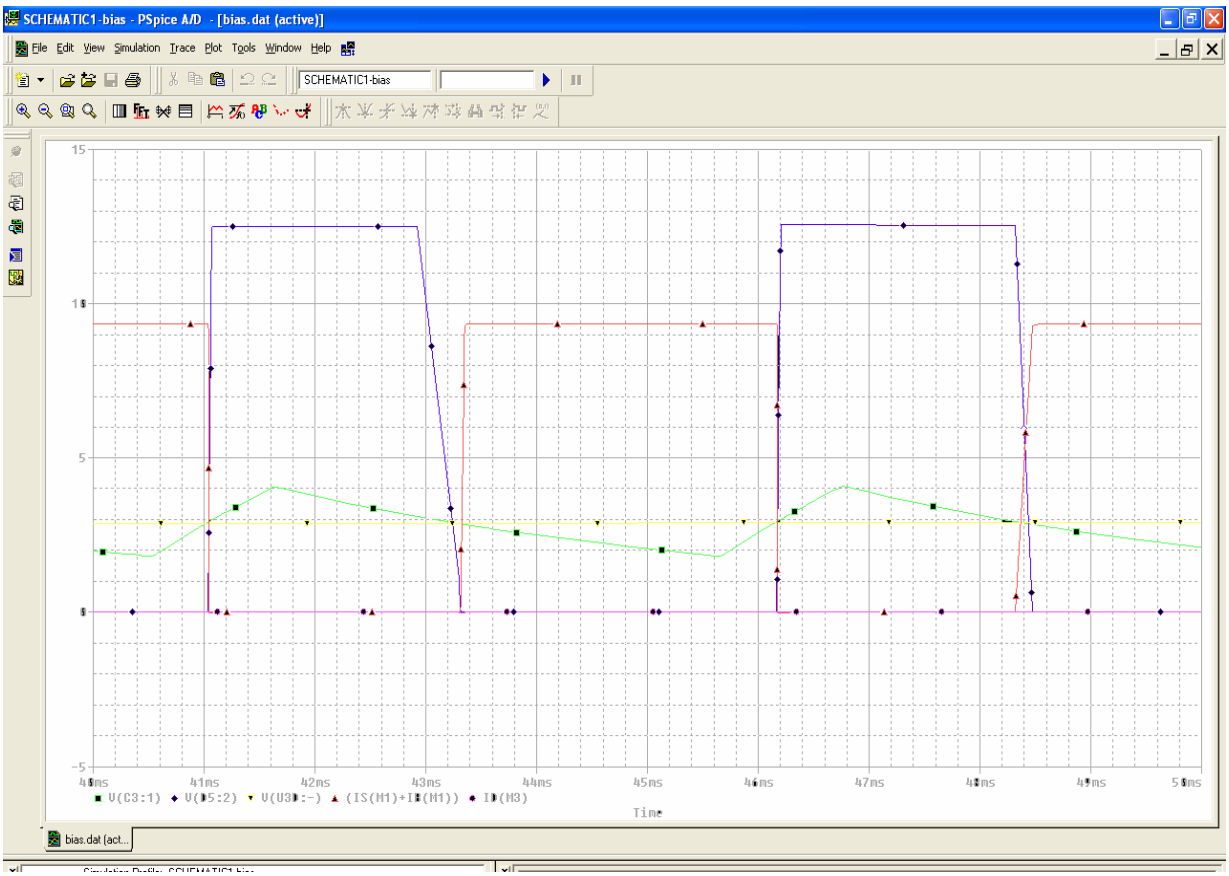


Figure 42: MOSFET Switching Response to PWM

After parts are ordered and are sent, the circuit will be physically constructed on a protoboard and it will be tested using a digital multimeter and oscilloscope. The multimeter will be used to ensure that the reference voltages are correct, and the oscilloscope will display the voltages across the terminals shown in Figure 42 (above) similar to PSPICE.

2.2.2.5. Electric Motor

The electric motor used to drive the bed, back up and down will be a variable speed series wound DC motor. In this motor, the stator and rotor are connected in series across the voltage source (see Figure 24, page 25), producing equal operating current in both. This circuit (see Figure 31, page 34) design uses pulse width modulation (PWM) to control the speed of the motor. As it was explained previously, the greater the voltage, the faster the motor runs causing the actuator to rise or lower faster, and visa versa with less voltage. Depending on the polarity of the voltage, this will determine which way the rotor or armature rotates. Positive voltage will cause the rotor to rotate such that it drives the actuator up and raise the bed. Negative voltage will rotate the rotor in the

opposite direction and cause the actuator to retract and lower the bed. The major drawback of this motor type is that if a "no load" condition occurs ("zero torque speed"), the motor could accelerate beyond its mechanical design limit and fail [10]. However, this will never happen in this device because there will always be some load on the system due to the weight of the bed back. In choosing a motor, an appropriate revolution speed, in rotations per minute (RPM), must be found and the motor must be able to handle the voltage outputted by the circuit. This can be tested by supplying a range of DC power to the motor and measuring the RPMs by the use of a tachometer to verify its speed. For proper operation, the torque and horsepower need to be calculated and can be determined with Equation 1.

$$Power(hp) = \frac{torque(ft * lb) * angularspeed(rpm)}{5252} \qquad \text{Eq 1 [12]}$$

2.2.2.6. Actuator

The actuator converts the rotational motion of the electric motor into linear motion to drive the bed back, up and down. This is typically done through the use of a lead screw or worm gear drive. As shown in Figure 25, page 26, the motor drives the lead screw in a circular motion. Due to the threading on the lead screw, and the load nut, this circular motion is transformed into linear motion as the load inches up the threading with each full rotation of the lead screw. The roles of the load nut and the lead screw can be reversed should the operation require it. In such a case, the motor would rotate a fixed threaded nut, in which the lead screw would sit. The load would then be placed at one end of the lead screw. As the nut is rotated by the motor, the lead screw will be forced through it, in one direction or the other, via the threading on each. This in turn would then drive the load upwards.

The rate of linear motion performed by an actuator such as this is a function of the revolution speed of the motor, in revolutions per min (rpm), and the pitch of the thread, in inches per revolution (in/rev), as shown in Eq 2.

$$V = threadpitch * angularspeed \qquad \text{Eq 2}$$

With each turn of the nut, the lead screw will travel a distance equal to the pitch value of the thread. Therefore, the faster the motor spins, the faster the load is moved.

In this design, a ball lead screw will be used turned by an electric motor, and used to pull together the sides of a scissor jack. During this contraction, the

scissor jack pushes up on the bed back, raising the angle. This set up is shown in Figure 43.

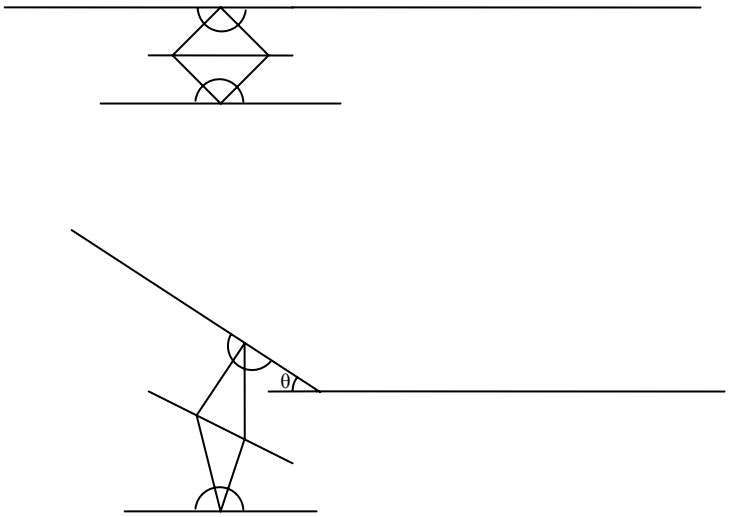


Figure 43: Diagram of Scissor Jack Lifting Bed Back

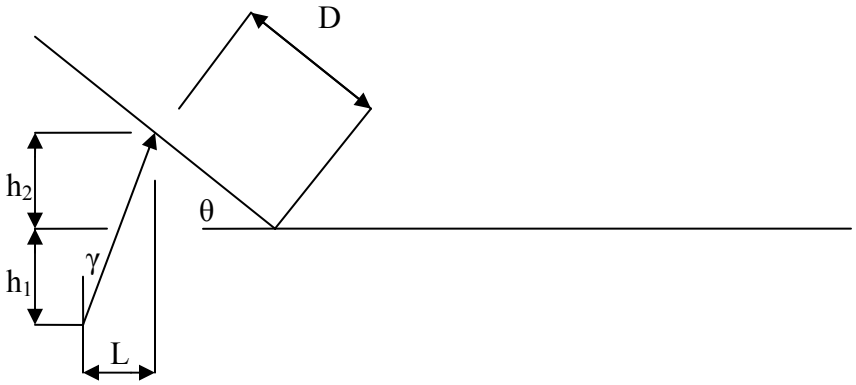


Figure 44: Free Body Diagram of Lifting System

Where:

h_2 = Raise in bed at θ degree incline (D*sin(θ))
h_1 = Length of Fully Retracted Scissor Jack
θ = degree incline in bed back
D = Distance of connection point from bed joint
γ = degree tilt of actuator at θ degree incline in bed back $\left(\tan^{-1}\left(\frac{L}{h_1+h_2}\right)\right)$

L = horizontal displacement of connection point (D*cos(θ))

Assuming that the force from the patient's weight is focused at about 1/3 of the length of the bed back, 35 inches in length, from the joint we assume that F is concentrated at D=15 inches. Therefore, the actuator will also be placed at this point so that the majority of the weight is directly supported. The bed is also projected to lift from 0 degrees to 70 degrees of incline. Therefore, the actuator will be under the greatest tensile and shear stresses while at its maximum amount of incline. To determine the proper material and diameter for the actuator shaft, we assume the maximum load of 180 pounds is applied at the connection. Knowing the force applied at the joints, the proper mounting brackets must be used to compensate for movement of the actuator as its angled. The clevis bracket will be pinned to both ends of the actuator to provide a sturdy attachment and allow for pivoting as the bed back angle changes. From Figure 44, on previous page, we can calculate the required increase in the scissor jack height by calculating h_2. Since D=15 inches, and θ = 70°, h_2 = 15*sin(70°) = 15 inches.

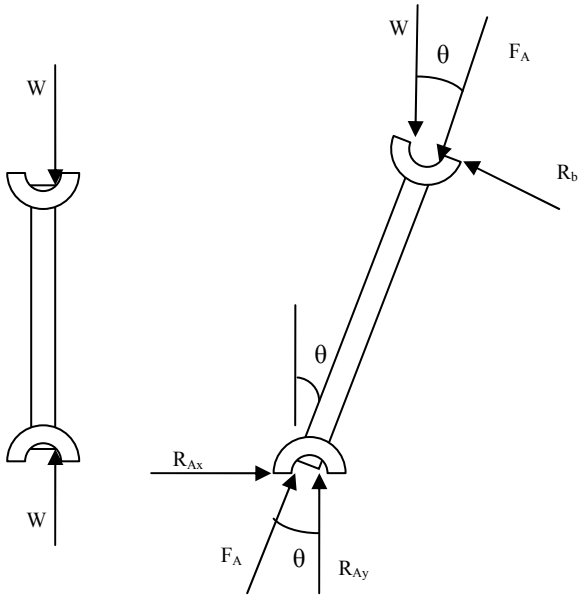


Figure 45: Free Body of Scissor Jack (Assuming Scissor Jack is a Rigid Body)

Where:

W = Weight of the patient
θ = Change in angle of bed back (in degrees)
F_A = The axial force in the Scissor Jack $\left(F_A = W * \cos[\theta]\right)$
R_b = Reaction of the bed back $\left(F_A = W * \sin[\theta]\right)$
R_{Ax} = Reaction of support in x-direction $\left(R_{Ax} = F_A * \sin[\theta]\right)$
R_{Ay} = Reaction of support in y-direction $\left(R_{Ay} = F_A * \cos[\theta]\right)$

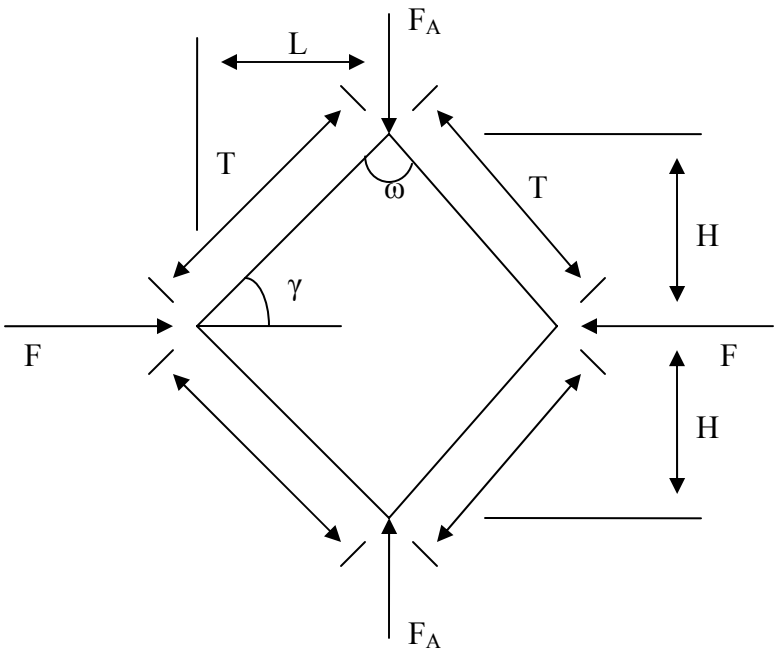


Figure 46: Diagram of Forces on Scissor Jack

The following equations are used to calculate the force applied by the lead screw.

$$\gamma = \sin^{-1}\left(\frac{H}{T}\right) \qquad \textbf{Eq 1}$$

$$\Delta L = T * \left(\cos(\gamma_{70}) - \cos(\gamma_0)\right) \qquad \textbf{Eq 2}$$

$$F = \frac{F_A * \cos(\gamma)}{\sin(\gamma)} \qquad \textbf{Eq 3}$$

Where:

F_A = The axial force in the Scissor Jack (From Figure 46)
T = Length of each Arm of Scissor Jack
F = Force Applied by Lead Screw
H = Half Height of jack
L = Half the width of the jack
ΔL = Change in L between 70 degree bed angle and 0 degree be angle
γ_{70} = Angle at 70 degree bed angle
γ_0 = Angle at 0 degree bed angle

In our design, the maximal force on the scissor jack will occur at an angle of 0°. Therefore, we use this case to determine the maximum power required by

the motor. In this case, F_A = W, for which 200 lbs can be used for a patient weight of 180 lbs and compensating for the weight of the bed. Also, T = 11 inches, and H at 0° is 2.5 in. By plugging these numbers into Equations 1 and 2, we find that the force required (F) is 852.74 lbs.

The following equations are use to calculate the torque and power required to drive the scissor jack at the required rate.

$$T = 0.177 * F * \rho \qquad \textbf{Eq 4 [14]}$$

$$P = \frac{F * \rho * n}{3.564 \times 10^5} \qquad \textbf{Eq 5 [14]}$$

Where:

T = The torque required by the motor
F = Force Applied by Lead Screw
ρ = Thread pitch (in/rev)
n = Desired rotational speed (rpm)

Since we know F, only the thread pitch (ρ) and the rotational speed (n) needs to be determined. To get a 70 degree raise in the bed angle, we need the scissor jack to 16 inches. This means that H will go from 2.5 inches to 10.5 inches. Using these values, we can find the change in 2L (2*ΔL) for which the screw will travel. This value comes out to be 15 inches. At the maximum speed, we would like the bed to travel from flat to a 70 degree raise in 3 seconds, which means a velocity in the screw of 5 inches/sec. By trial and error, and the use of Figure 47 on next page, we found out the thread pitch should be 0.5 in/rev, and a 1 in diameter screw as shown in Figure 48 on next page. Therefore, to accomplish a 5 in/sec travel, the rotational speed would have to be $\frac{5\,\text{in/sec} * 60\text{sec/min}}{0.5\,\text{in/rev}} = 600 rev/\min$. Therefore, the torque required (T) will be 75.5 ft*lb, and the power (P) will be 0.718 hp.

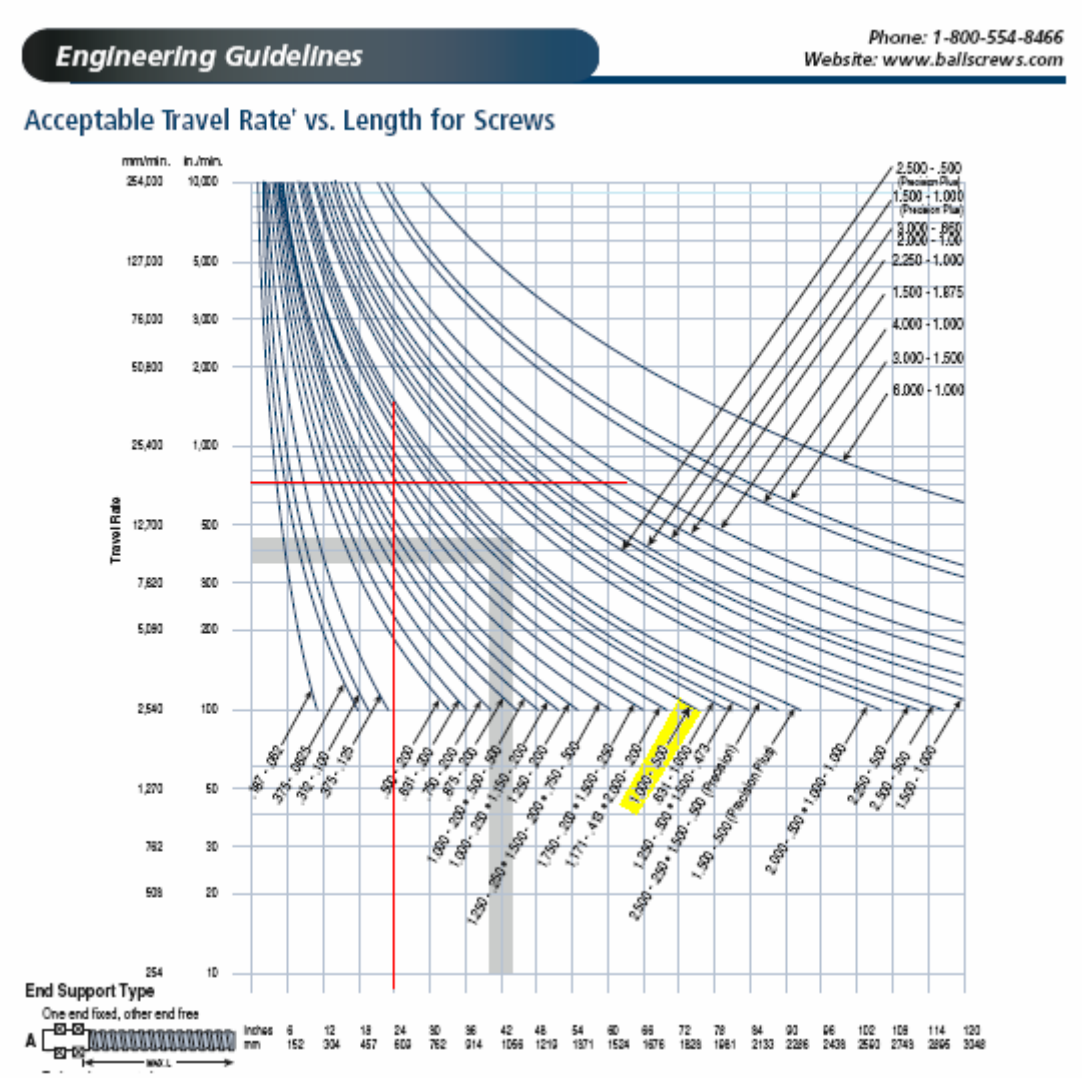


Figure 47: Acceptable Travel Rate vs. Length for screws [14]

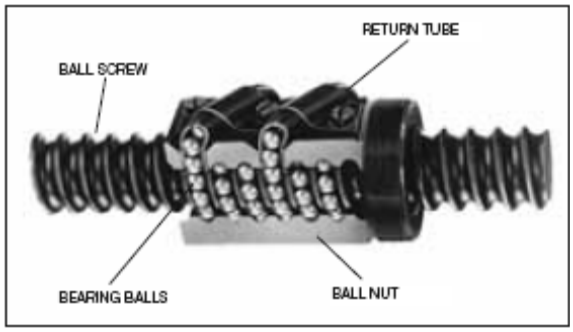


Figure 48: Ball Screw [14]

Knowing the force applied at the joints, the proper mounting brackets must be used to compensate for movement of the rod as its angled. The clevis bracket (Fig. 29, page 30) will be pinned to both ends of the Al-Be 80/20 rod to

provide a sturdy attachment and allow for pivoting as the bed back angle changes.

2.2.2.7. Support Frame

After understanding all the loads that this device needs to withstand, a strong support frame for the actuator can be determined. The most practical metal to use in this situation is Aluminum-Beryllium (Al-Be) 80/20. This is a light weight, durable, easy to assemble, and cheaper way to construct this verse welding steel parts together. Figure 30, page 31, is a picture of Al-Be 80/20 and chart of its mechanical properties. The design of this structure is seen in the overview of the frame in Figure 49 and 50 on pages 60 and 61, respectively. This material will be ordered in the proper sizes and put together in the machine shop. Once the frame is finished, it will undergo a series of loading tests to test the strength of the structure. If failure is to occur, reinforcement will be added where necessary.

The overall schematic of the design (as illustrated in the Microsoft VISIO drawings in Figures 23 and 24) demonstrates the pivoting of the actuator to allow for movement as the bed is operated and sustains a low profile when retracted. Also, the handle is positioned out of the way and designed for easy access. All parts are secured with bolts to the frame of the bed or the Aluminum. To demonstrate the final workings of this automatic back angle controller, it will be fastened to a mock bed platform. It can be made out of scrap Al-Be 80/20 or welded with steel and have a metal platform attached to mimic the mattress. This will allow the device to be tested under the weight of humans lying on the platform.

14.2.3. Testing the Design

Once the subunits are assembled to create the bed back angle controller, the device needs to be tested for its functionality and reliability to ensure its safety. The handle design will undergo testing in the springs and the safety switch. The resistance springs must deflect the lever from its center position the correct amount without loosing their resilience. The spring constants will be tested by showing that when a 20 lb weight is hung from them, only one inch of the spring is stretched out. The safety switch of the handle is wired into the circuit and cuts off the power to the motor until the switch is turned on. This can be tested once the circuit is working properly. The circuit will be physically constructed on a protoboard and it will be tested using a digital multimeter and oscilloscope. The multimeter will be used to ensure that the reference voltages are correct, and the oscilloscope will display the voltages across the terminals. To ensure the motor is not drawing in a dangerous level of current from the circuit,

the size of the worm gear lead screw is chosen specifically to not require a high level of torque to be powered. To confirm the torque and power needed by the motor to operate the scissor jack, the pitch of the screw can be measured with a ruler and it can be calculated with Equations 4 and 5.

When the basic components are tested individually the device can then be assembled and tested as one unit. The handle design must be correctly wired to the motor. The motor must be secured onto the scissor screw jack and the screw jack must be properly attached to the frame of the bed back with pivoting mounting brackets. This device is setup on a prototype bed platform that will enable us to test its ability to adjust the back angle. The final test for the true workings of this device is to have a person lie down on the bed and operate the handle in both directions.

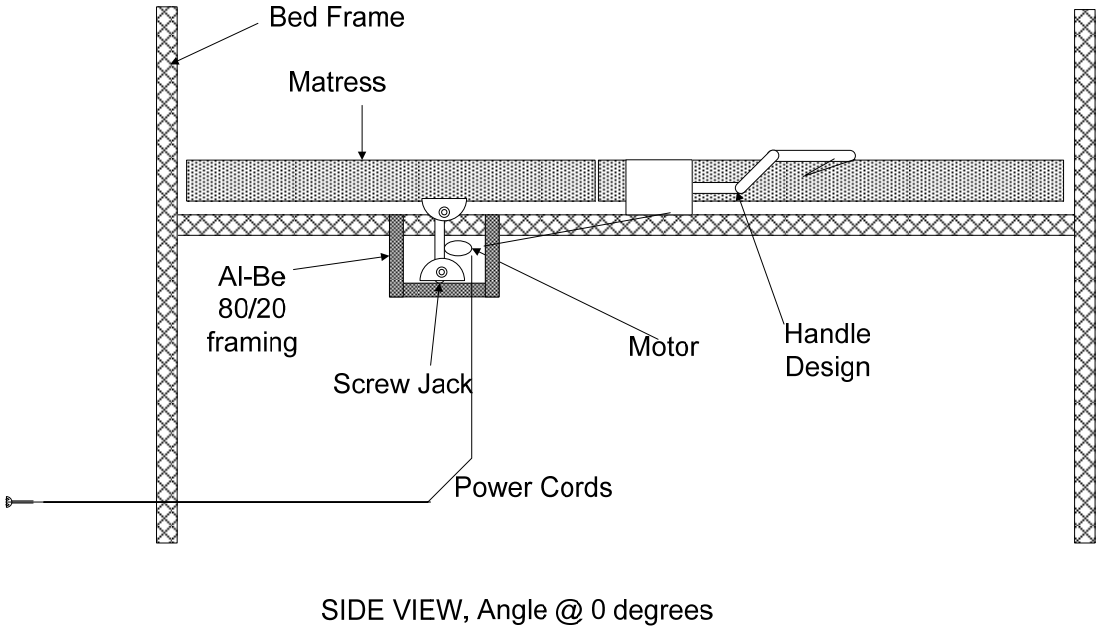


Figure 49: Overall Schematic at Zero degrees Angle for Optimal design

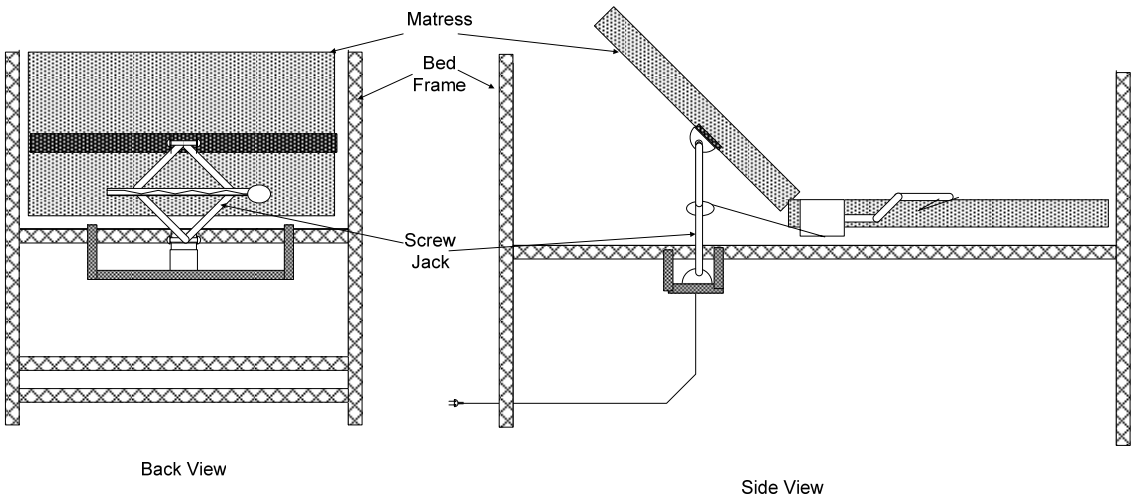


Figure 50: Overall Back and Side Schematic at 70 degrees Angle for Optimal Design

15. Realistic Constraints

Naturally, when designing a new device, there will be some constraints. The only ethical concern is that this device must be designed with the patients and users safety in mind. Safety precautions are addressed in detail in the international standards and in the section below. For this design all materials used must be durable so that they can lift and hold up to 200lbs, be readily available, environmentally safe and be able to be sterilized. The rod that is being pushed by the screw drive actuator needs to be supported by a frame when being attached to the back. Otherwise, if too much force were applied to the rod and it was positioned in the middle of the bed back, it may break through the bed mattress, and in its worst case, stab the patient in the back.

With the implementation of the brush series wound DC motor, there are concerns about the longevity of the brushing mechanism. However, this is not a major issue because it still has a considerable life span, especially for this low impact situation. With any load bearing device, the wear and tear on the screws and fixtures will also be a concern with the devices sustainability. Finally, the availability of the parts used in manufacturing the device was considered and it will be economically feasible for mass production.

According to internationally recognized quality and safety standards, there are some constraints to consider when designing. The International Standards Organization (ISO) [18] and the International Electrotechnical Commission (IEC)

develops rules to follow in order to reassure that the product is reliable and will meet expectations in terms of performance, safety, durability and other criteria. The following standards were taken from the IEC website because they closely match the building requirements of the adjustable bed design [19]:

- **IEC 60073 Basic and safety principles for man-machine interface, marking and identification - Coding principles for indicators and actuators.** Establishes general rules for assigning particular meanings to certain visual, acoustsic and tactile indications. Has the status of a basic safety publication in accordance with IEC Guide 104.
- **IEC 60364-4-41 Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock.** Specifies essential requirements regarding protection against electric shock, including basic protection (protection against direct contact) and fault protection (protection against indirect contact) of persons and livestock. It deals also with the application and co-ordination of these requirements in relation to external influences. Requirements are also given for the application of additional protection in certain cases.
- **IEC 60447 Basic and safety principles for man-machine interface, marking and identification - Actuating principles.** Establishes general actuating principles for manually operated actuators forming part of the man-machine interface associated with electrical equipment, in order to increase the safety through the safe operation of the equipment and facilitate the proper and timely operation of the actuators
- **IEC 60529 Degrees of protection provided by enclosures (IP Code).** Applies to the classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72.5 kV.
- **IEC 60534-6-1 Industrial-process control valves - Part 6: Mounting details for attachment of positioners to control valves - Section 1: Positioner mounting on linear actuators.** Intended to permit a variety of positioning devices, which respond to a linear motion, to be mounted on the actuator of a control valve, either directly or by employing an intermediate mounting bracket. Applicable where interchangeability between actuators and positioners is desired.
- **IEC 60601-1 Medical Electrical Equipment: General Requirements for Safety.** Applies to the safety of medical electrical systems, as defined as follows: combination of items of equipment, at least one of which must be medical electrical equipment and inter-connected by functional connection or use of a multiple portable socket-outlet. Describes the safety requirements necessary to provide protection for the patient, the operator and surroundings. Cancels and replaces the first

edition published in 1992 and its amendment 1 (1995) and constitutes a technical revision.

- **IEC 60601-1-2 Top Level standard for electromagnetic compatibility for electrical medical equipment.**
- **IEC 60601-1-6 Medical electrical equipment - Part 1-6: General requirements for safety - Collateral standard: Usability.** This Collateral Standard describes a usability engineering process, and provides guidance on how to implement and execute the process to provide medical electrical equipment safety. It addresses normal use and use errors but excludes abnormal use.
- **IEC 60601-2-38 Particular requirements for the safety of electrically operated Hospital beds.** Specifies requirements for safety of electrically operated hospital beds. The object of this standard is to keep the safety hazards to patients, operators and the environment as low as possible, and to describe tests to verify that these requirements are attained.
- **IEC 60601-2-46 Medical electrical equipment - Part 2-46: Particular requirements for the safety of operating tables.** Specifies safety requirements for operating tables, whether or not having electrical parts, including transporters used for the transportation of the table top to or from the base or pedestal of an operating table with detachable table top.
- **IEC 61800-1 Adjustable speed electrical power drive systems - Part 1: General requirements - Rating specifications for low voltage adjustable speed DC power drive systems.** Applies to general purpose adjustable speed DC driven systems which include the power conversion, control equipment, and also a motor or motors. Excluded are traction and electrical vehicle drives. Applies to power driven systems (PDS) connected to line voltages up to 1 kVAC, 50 Hz or 60 Hz.
- **IEC 62955-1 Primary batteries - Summary of research and actions limiting risks to reversed installation of primary batteries.** Provides information relevant to the safe design of batteries and battery powered devices together with appropriate cautionary advice to consumers. This report is primarily intended to be used by battery manufacturers, equipment manufacturers, designers, standard writers, consumer organizations, and charger manufacturers. This report may also be of assistance to educational authorities, users, procurement personnel, and regulatory authorities.

16. Safety Issues

As with all engineering projects, the safety of the hospital bed's user is paramount. This project is designed for widespread use, and if even one patient or caretaker is significantly injured, then it is a failure. The device will be employed in hospitals where children will be, as well as those with reduced

coordination and muscle control, so the exposed parts will be rounded off to prevent significant lacerations and contusions from collision. Another basic safety feature is the absence of exposed joints that can cause pinching if someone's hand is in the wrong place at the wrong time. Between January 1, 1985 and January 1, 2006, FDA received 691 incidents of patients caught, trapped, entangled, or strangled in hospital beds. The reports included 413 deaths, 120 nonfatal injuries, and 158 cases where staff needed to intervene to prevent injuries. Most patients were frail, elderly or confused [20]. Also, the Center for Disease Control and Prevention reports that in 1995, five out of every 100 admissions into a hospital in the United States resulted in a nosocomial infection [21]. These hospital-acquired infections resulted in 88,000 deaths in that year alone. In order to control the spread of bacteria and viruses between bed users, the exposed parts will all be made of easily-sterilized aluminum.

More advanced safety issues have also been taken into account. In the frenzied activity of the hospital, it is certain that someone will accidentally bump into the control handle, and the bed should not be adjusted under those circumstances. A safety lock system will be implemented in order to avoid this. On the underside of the end of the handle there will be a long lever similar to a bicycle brake lever which must be depressed in order for the system to act on any movement of the handle. This lever will be easily pressed so that those who cannot exert much pressure with their fingers, such as those with arthritis and Parkinson's, will be able to operate it. The maximum speed that the bed can be raised and lowered is also important for the safety of the patient. If the bed back is adjusted too quickly, further injury or disorientation is possible depending on the state of the patient. This maximum speed is regulated by the simple circuit design attached to the rheostat that measures the variable forces applied to the handle. The absolute maximum will be set at a safe level for those that are not in a fragile state, but can be easily set lower to protect those that are in critical condition.

The mechanical actuator lift must also be safe. Due to its position in a contained area underneath the bed, physical contact with the patient and others will be minimal. Even so, the electrical wiring will be insulated and fuses will be included for safety in the event of a power surge. The wires will be protected so that no electrical shock will occur per the IEC 60364-4-41 standard mentioned above. In the event of a power loss, a back-up battery will be implemented per the safety standards of IEC 62955-1. The circuit has also been carefully designed so that the motor cannot draw a dangerous amount of current from it and in worst cases become a fire hazard. So, all precautions have been taken to ensure that the patient is protected from the electricity. Also, if power is lost, the bed will remain in its current position instead of suddenly falling to horizontal. This

is an advantage to a mechanical actuator because it will not budge from its position unless a voltage is applied to the motor to give it power again.

Of course before any product is marketed, there are a series of validation steps that include vigorous testing procedures, specifications, and standards to be met in order for the product to be considered safe for public use. The IEC has set some recommended guidelines to be followed for the Technical Reports (TR) to ensure it is tested properly. Below are a few safety issues, in compliance with the standards mentioned above, to be considered during development—especially if this device is marketed.

- **ISO/IEC GUIDE 46: Comparative testing of consumer products and related services - General principles.**
- **IEC/TR 62354 General testing procedures for medical electrical equipment.** This Technical Report applies to medical electrical equipment as defined in IEC 60601-1. Its object is to provide guidance on general testing procedures according to IEC 60601-1.
- **IEC/TR 62296 Considerations of unaddressed safety aspects in the Second Edition of IEC 60601-1 and proposals for new requirements.** This Technical Report is primarily intended to be used by: manufacturers of medical electrical equipment, test houses and others responsible for assessment of compliance with IEC 60601-1, and those developing subsequent editions of IEC 60601-1.
- **IEC 61310-3 Safety of machinery - Indication, marking and actuation - Part 3: Requirements for the location and operation of actuators.** Specifies safety-related requirements for actuators, operated by the hand or by other parts of the human body, at the man-machine interface. Gives general requirements for: - the standard direction of movement for actuators; - the arrangement of an actuator i relation to other actuators; - the correlation between an action and its final effects. Based on IEC 60447, but is also applicable to non-electrotechnical technologies. Covers single actuators as well as groups of actuators forming part of an assembly.
- **IEC/TR 61258 Guidelines for the development and use of medical electrical equipment educational materials.** Outlines a generic process for developing materials for education and training of operators of medical electrical equipment. It may be used by standards organizations, manufacturers, regulatory agencies, hospital managers, physician and nurse educators, and others involved directly or indirectly in education and training of users/operators.
- **IEC 61123 Reliability testing - Compliance test plans for success ratio.** Specifies procedures for applying and preparing compliance

test plans for success ratio or failure ratio. The procedures are based on the assumption that each trial is statistically independent.

- **IEC 60605-2 Equipment reliability testing - Part 2: Design of test cycles.** It applies to the design of operating and environmental test cycles.

17. Impact of Engineering Solutions

Our design project is a portable, easily-installed or removed, cost-effective, automatic lift mechanism. It has been designed with a "universal fit" in mind for basic hospital bed models, with or without side railing. The lift mechanism may be safely installed in convenient locations for operation by the patient as well as the caregiver. The lift mechanism is adaptable to meet changing needs of the patient. Our design meets internationally recognized quality and safety standards for medical equipment.

The automatic lift mechanism is inherently cost-effective for health care facilities since it can be purchased independent of the hospital bed. If the automatic lift feature is desired, purchase of new beds having the feature "built-in" will not be necessary as replacement of existing standard or basic hospital beds is not necessary. As necessary for patient care, the health care facility would have the option of either installing the lift mechanism on existing beds or purchasing new standard, less expensive beds and installing the lift mechanism.

The availability of our automatic lift mechanism for standard hospital beds in clinics or hospitals around the world can positively affect the health care setting in terms of allowing the patient more independence from the caregiver supervision. The societal common good would be served by narrowing the gap between basic health care equipment in the U.S. versus that in third world countries.

Our design or product's cost impact to health care facilities, exiting and new, is exemplified per the following. Our design has the estimated retail price of less than $313 (refer to budget Table 1). A standard bed (e.g., manual crank lift by *A1 Adjustable Beds*) is listed as $712 [22]. The price of a deluxe hospital bed model number SS3TPKGTM by *A1 Adjustable Beds*, with the automotive lift mechanism as well as other, possibly unnecessary features, is listed as $3200 [23]. Installing our automatic lift mechanism on new standard hospital beds vs. purchasing a deluxe hospital bed is estimated to be $2175 cost savings. Savings can be considerable for a small clinic; purchase of 15 new basic beds and the automatic lift mechanism, will yield an estimated savings of $32,621. If use of *existing, standard* beds is possible, purchase of only the lift mechanism is necessary to receive the same. The savings of course can be used to purchase other equipment or supplies, especially beneficial for non-profit organizations.

The Adjustable Back Angle Controller will make the lives of many around the world much easier. From nurses and aids to patients suffering from a wide range of afflictions, ranging from blindness to any number of diseases causing tremors and the lost of motor skills. In particular, our design is capable of assisting each of our clients and wide range of disabilities.

Every day, people develop back pain as a result of their occupation, injury or life style. Occupations such as nursing and home aids are of the most likely to develop some kind of back problem. This is mostly due to the constant repositioning of patients to prevent bed sores or for therapies. With patients suffering from back pain, an inclined back position provides some relief as well as helping to improve the patient's condition. Persons with obesity can often have trouble breathing while laying fully reclined position, however raising their resting angle up will open the air ways allowing for easier breathing. It is also difficult for the elderly, obese or sufferer of other debilitating conditions to simply get out of bed while laying flat. This often means that a nurse of aid must assist the individual in sitting up, and stabilize them while getting off the bed. An adjustable bed, however, allows either the patient or the aid to life the patient's back into an inclined position, relieving the aid of any strain on their back while bending over the bed, and assisting the individual to sit up. An adjustable bed is very useful in all of these cases, and often makes the caretaker's job much less strenuous.

With the aid of our Adjustable Bed Angle Controller, these benefits can be enjoyed by individuals such the clients Matt and Akiko, who have vision problems. With our design, it will be much easier for the blind or visually impaired. This is made possible because the lever will always be in the same position, while still remaining out of the way. In addition, instead of fumbling with button, our design allows the patient to operate the bed by pushing the lever down to lower the bed, and up to raise the bed. This intuitive design will allow all users to operate the bed without the learning curve required to learn where each button is located, and the functions they provide.

Many people suffer from conditions which affect their motor skills. Conditions such as severe arthritis as well as Parkinson's disease greatly diminish an individual's manual dexterity as well as their ability to grasp small object. The operation of a handle which requires minimal grasping power, and no dexterity to move, as opposed to a wired remote control with numerous small buttons required to operate the bed, would be of great benefit to individuals such as our client Lakisha who suffers from Parkinson's disease.

The Adjustable Back Angle Controller will be a very affordable alternative to the typical fully-electric adjustable bed. With an estimated retail price of $313, combined with its smooth operation, infinitely adjustable speed, and ergonomic and intuitive control, the functionality is well worth the price tag. The costs of production are kept down by the use of existing parts, but combined in a manner which allows for new and better operation of an existing product.

18. Life-long Learning

Work on this project has expanded the knowledge of the engineering students. Much research was required to understand the problems associated with this design. New material and techniques were acquired such as the concept of *extended physiological proprioception* (EPP). This concept implies that devices should react to the user's input in an intuitive manner, creating the sensation that it is an extension of the user's own body. EPP was integrated into the device through the force-sensitive handle that changes the pressure within the closed hydraulic system.

In order to design a handle that is used to detect the force placed upon it, many different methods were considered. There are many ways to detect the forces placed on an object, but thus far there has not been a handle constructed for this purpose. While exploring the options for this part, the first idea used load cells to detect the force, since they were used in Biomechanics lab to measure the tension force on various objects. After looking into load cells by visiting various commercial and educational websites, it became apparent that most load cells are not designed to detect the small forces required by this project. Also, they are relatively expensive and would deplete the budget for the project. Another rejected idea involved strain gauges to detect force. The functional part of a strain gage is a resistor that changes value when it is stretched or compressed. A supporting circuit applies a constant DC voltage to the gage and also detects the voltage output from the sensor [24]. The gage would be attached near the base of the handle to determine the force by detecting the extent that the metal is deformed. Research into strain gages showed that they could be calibrated to detect force in the desired range, but the conditions of the handle had to be held constant to a degree not acceptable in the public setting that the device will be used. For instance, strain gages must be kept at a constant temperature in order to make correct readings, and their resistance also changes with time, so the supporting electrical circuit would need to be adjusted regularly. The optimum design for the handle uses springs in a way to translate the force placed on the handle into a displacement angle that directly influences the resistance input to the circuit.

Another major system learned was the basics of hydraulics. Hydraulic circuits are similar to electric circuits. In fact, pressure can be analyzed exactly like voltage by Kirchoff's voltage law. Pascal's law is also very important to operation of the device. Pascal's law states that $P_2-P_1=-\rho g(h_2-h_1)$, where P refers to the pressure, ρ is the density of the liquid, g is the acceleration due to gravity, and h is the height of the liquid. This law is significant because it means that pressure is transmitted thru a closed circuit undiminished. This allows the circuit relying on the hydraulic pressure to operate with a relatively simple design. However, as the hydraulic design progressed, it became clear that the system would be too complex, bulky, messy, and generally not hospital-friendly.

The optimal design being considered uses a variable speed DC motor to drive a mechanical scissor jack actuator. The DC motor must be series wound so that a change in the voltage supplied to it would change the speed that the motor works, which in turn changes the rotation of the worm screw, driving the scissor jack. The jack is driven by ball screws for a smoother and more efficient operation. Through this Life-long learning process, engineers constantly discover new and better ways to solve a problem. This will in the end result in the most efficient design.

After working through three designs for this project, it is clear that life-long learning is a lesson well-learned. The trials and error in designing alone helped our group expand on our knowledge of how to prepare for such a project. It is extremely important to carefully consider details now, in the learning stage, rather than later in the building stage. Had we stuck to our original design of hydraulics, we may not have discovered the difficulty of creating such a system until the device started to fail or leak fluid. Or even our previous design of a linear actuator may not have been stable enough to function properly. This optimal design may not be perfect either, but we know that we have learned from our past mistakes by improving our design and found that it takes a lot of careful thought and consideration to build any device. This project has shown us that regardless of how much we think we know we must still learn new material in order to accomplish even the simplest of tasks.

Another essential lesson learned is the importance of working as a multidisciplinary team. A project that is as complex as this one cannot be completed successfully by just one engineer. It takes a group of engineers pooling their skills to accomplish this task. Working in a group like this has developed teamwork skills that are required for a successful engineering career. Over the course of the design stage of the project, work has been divided between the three members of the team, checked for errors by the other members, adjusted due to changes in other parts of the design, and brought

together into a single device. This process has prepared the team members well for future projects during their careers.

19. Budget and Timeline

19.1. Budget

Table 3: Estimated Budget

Company & Parts	**PO Req. Number***	**Price**
Aluminum for Handle and Control Box	N/A	About $50
Camping World – Scissor Jack	1	$100.98
Digi-Key Corp. - Mosfets	2	$18.60
Lee Spring – Compression Springs	3	$68.90
The Home Depot – Bed Frame Supplies	4	$18.33
Estimated Total Cost		***$256.81***

**Refer to 12.2 for PO Requisitions Numbers*

19.2. Timeline

Table 4: Timeline

ID	Task Name	Duration	Start	Finish	Names
1	Final Report	6 days	11/20/2006 8:00	11/27/2006 17:00	
2	Machine Shop Certification	5 days	11/27/2006 8:00	12/1/2006 17:00	
3	Update Website	3 days	11/27/2006 8:00	11/29/2006 17:00	
4	Finalize Parts Order	5 days	12/4/2006 8:00	12/8/2006 17:00	
5	Prepare Final Presentation	3 days	12/4/2006 8:00	12/6/2006 17:00	
6	Final Presentation	1 day	12/8/2006 8:00	12/8/2006 17:00	
7	Order Parts	5 days	12/4/2006 8:00	12/8/2006 17:00	
8	Start to Receive Parts	4 days?	1/16/2007 8:00	1/19/2007 17:00	
9	Prototype Bed With Scissor Jack	4 days	1/16/2007 8:00	1/19/2007 17:00	Steve
10	Order Scissor Jack	4 days	1/16/2007 8:00	1/19/2007 17:00	

11	Receive Scissor Jack	4 days	1/16/2007 8:00	1/19/2007 17:00	
12	Measure and test Scissor Jack	4 days	1/16/2007 8:00	1/19/2007 17:00	Steve
13	Finish Bed Frame Design	1 day	1/18/2007 8:00	1/18/2007 17:00	Alaena
14	Order Framing	4 days	1/16/2007 8:00	1/19/2007 17:00	
15	Write Weekly Report	1 day	1/19/2007 8:00	1/19/2007 17:00	
16	Update Website	1 day	1/19/2007 8:00	1/19/2007 17:00	
17	Weekly Meeting	1 day	1/19/2007 8:00	1/19/2007 17:00	
18	Calculate RPM required by Motor	5 days	1/22/2007 8:00	1/26/2007 17:00	Steve
19	Test Force Required to Extend Jack	5 days	1/22/2007 8:00	1/26/2007 17:00	Steve
20	Order Springs	1 day	1/23/2007 8:00	1/23/2007 17:00	
21	Write Weekly Report	1 day	1/26/2007 8:00	1/26/2007 17:00	
22	Update Website	1 day	1/26/2007 8:00	1/26/2007 17:00	
23	Weekly Meeting	1 day	1/26/2007 8:00	1/26/2007 17:00	
24	Receive Framing	5 days	1/29/2007 8:00	2/2/2007 17:00	
25	Measure and Cut Framing	5 days	1/29/2007 8:00	2/2/2007 17:00	Alaena
26	Machine Bed Frame	5 days	1/29/2007 8:00	2/2/2007 17:00	Alaena
27	Write Weekly Report	1 day	2/2/2007 8:00	2/2/2007 17:00	
28	Update Website	1 day	2/2/2007 8:00	2/2/2007 17:00	
29	Weekly Meeting	1 day	2/2/2007 8:00	2/2/2007 17:00	
30	Receive Springs	1 day	2/2/2007 8:00	2/2/2007 17:00	
31	Test Springs	5 days	2/5/2007 8:00	2/9/2007 17:00	Steve & Alaena
32	Machine Handle	5 days	2/5/2007 8:00	2/9/2007 17:00	Alaena
33	Develop Test Plan of Circuit	5 days	2/5/2007 8:00	2/9/2007 17:00	Ray
34	Test Individual Circuit Components	5 days	2/5/2007 8:00	2/9/2007 17:00	Ray
35	Write Weekly Report	1 day	2/9/2007 8:00	2/9/2007 17:00	
36	Update Website	1 day	2/9/2007 8:00	2/9/2007 17:00	
37	Weekly Meeting	1 day	2/9/2007 8:00	2/9/2007 17:00	

38	Prototype Circuit	5 days	2/12/2007 8:00	2/16/2007 17:00	Ray
39	Test Prototype Circuit	5 days	2/12/2007 8:00	2/16/2007 17:00	Ray
40	Troubleshoot Circuit	5 days	2/12/2007 8:00	2/16/2007 17:00	Ray
41	Write Weekly Report	1 day	2/16/2007 8:00	2/16/2007 17:00	
42	Update Website	1 day	2/16/2007 8:00	2/16/2007 17:00	
43	Weekly Meeting	1 day	2/16/2007 8:00	2/16/2007 17:00	
44	Test Motor	5 days	2/19/2007 8:00	2/23/2007 17:00	Ray
45	Test Prototype Circuit with Motor	5 days	2/19/2007 8:00	2/23/2007 17:00	Ray
46	Design PCB in ExpressPCB	5 days	2/19/2007 8:00	2/23/2007 17:00	Ray
47	Order PCB	5 days	2/19/2007 8:00	2/23/2007 17:00	
48	Write Weekly Report	1 day	2/23/2007 8:00	2/23/2007 17:00	
49	Update Website	1 day	2/23/2007 8:00	2/23/2007 17:00	
50	Weekly Meeting	1 day	2/23/2007 8:00	2/23/2007 17:00	
51	Receive PCB	5 days	2/26/2007 8:00	3/2/2007 17:00	
52	Solder Parts to PCB	5 days	2/26/2007 8:00	3/2/2007 17:00	Ray
53	Test Soldered PCB	5 days	2/26/2007 8:00	3/2/2007 17:00	Ray
54	Troubleshoot PCB	5 days	2/26/2007 8:00	3/2/2007 17:00	Ray
55	Test Completed PCB with Motor	5 days	2/26/2007 8:00	3/2/2007 17:00	Ray
56	Construct Control Box	5 days	2/26/2007 8:00	3/2/2007 17:00	Alaena & Ray
57	Write Weekly Report	1 day	3/2/2007 8:00	3/2/2007 17:00	
58	Update Website	1 day	3/2/2007 8:00	3/2/2007 17:00	
59	Weekly Meeting	1 day	3/2/2007 8:00	3/2/2007 17:00	
60	Spring Break	5 days	3/5/2007 8:00	3/9/2007 17:00	
61	Implement Safety Lock Wiring	5 days	3/12/2007 8:00	3/16/2007 17:00	Ray
62	Put Together Control Box with PCB	5 days	3/12/2007 8:00	3/16/2007 17:00	
63	Attach Handle to Control box and PCB	5 days	3/12/2007 8:00	3/16/2007 17:00	
64	Attach Springs to Handle and Box	5 days	3/12/2007 8:00	3/16/2007 17:00	

65	Write Weekly Report	1 day	3/16/2007 8:00	3/16/2007 17:00	
66	Update Website	1 day	3/16/2007 8:00	3/16/2007 17:00	
67	Weekly Meeting	1 day	3/16/2007 8:00	3/16/2007 17:00	
68	Test Handle with PCB	5 days	3/19/2007 8:00	3/23/2007 17:00	
69	Attach Motor to Control Handle	5 days	3/19/2007 8:00	3/23/2007 17:00	
70	Test Control Handle and Motor	5 days	3/19/2007 8:00	3/23/2007 17:00	
71	Machine Jack Connections	5 days	3/19/2007 8:00	3/23/2007 17:00	Alaena & Ray
72	Write Weekly Report	1 day	3/23/2007 8:00	3/23/2007 17:00	
73	Update Website	1 day	3/23/2007 8:00	3/23/2007 17:00	
74	Weekly Meeting	1 day	3/23/2007 8:00	3/23/2007 17:00	
75	Assemble Jack to Bed Frame	5 days	3/26/2007 8:00	3/30/2007 17:00	Steve
76	Attach Motor to Jack	5 days	3/26/2007 8:00	3/30/2007 17:00	Steve
77	Attach Control Box to Bed	5 days	3/26/2007 8:00	3/30/2007 17:00	Alaena
78	Wire Control Box to Motor	5 days	3/26/2007 8:00	3/30/2007 17:00	Ray
79	Double Check Assembly of ABAC Parts	5 days	3/26/2007 8:00	3/30/2007 17:00	
80	Write Weekly Report	1 day	3/30/2007 8:00	3/30/2007 17:00	
81	Update Website	1 day	3/30/2007 8:00	3/30/2007 17:00	
82	Weekly Meeting	1 day	3/30/2007 8:00	3/30/2007 17:00	
83	Test For Accessibility for Disabled Clients	5 days	4/2/2007 8:00	4/6/2007 17:00	
84	Test for Blind Person Accessibility	5 days	4/2/2007 8:00	4/6/2007 17:00	
85	Test for Arthritic Person Accessibility	5 days	4/2/2007 8:00	4/6/2007 17:00	
86	Test for Obese Person Accessibility	5 days	4/2/2007 8:00	4/6/2007 17:00	
87	Test for Young Person Accessibility	5 days	4/2/2007 8:00	4/6/2007 17:00	
88	Test for Elderly Person Accessibility	5 days	4/2/2007 8:00	4/6/2007 17:00	
89	Test for Limited Mobility/Dexterity Person Accessibility	5 days	4/2/2007 8:00	4/6/2007 17:00	
90	Write Weekly Report	1 day	4/6/2007 8:00	4/6/2007 17:00	
91	Update Website	1 day	4/6/2007 8:00	4/6/2007 17:00	

92	Weekly Meeting	1 day	4/6/2007 8:00	4/6/2007 17:00	
93	Cosmetics	5 days	4/9/2007 8:00	4/13/2007 17:00	
94	Troubleshooting/ Catchup	5 days	4/9/2007 8:00	4/13/2007 17:00	
95	Write Weekly Report	1 day	4/13/2007 8:00	4/13/2007 17:00	
96	Update Website	1 day	4/13/2007 8:00	4/13/2007 17:00	
97	Weekly Meeting	1 day	4/13/2007 8:00	4/13/2007 17:00	
98	Write User Manual	5 days	4/16/2007 8:00	4/20/2007 17:00	
99	Final report	5 days	4/16/2007 8:00	4/20/2007 17:00	
100	Final Presentation	1 day	4/27/2007 8:00	4/27/2007 17:00	

20. Team Member Contributions to the Project

20.1. Team Member 1: Alaena DeStefano

Alaena has a concentration in biomaterials and has studied the importance of material selection; therefore her main contribution to this project is concerning the materials being used. She will primarily be responsible in the design and framework around the PCB, handle, and scissor jack as well as provide a prototype bed to mount this device to. Her work closely with her teammates will be important to the success of this project.

20.2. Team Member 2: Raymond Pennoyer

Ray is concentrating in Bioinstrumentation, which focuses on electronics. Because of this, he is developing the electric circuit. The design, testing, and troubleshooting of the circuit are also his responsibility. Another task assigned to him is the design of the PCB. He also will have completed the machine shop training, so he will help with machining parts as well.

20.3. Team Member 3: Steven Frisk

Steven is concentrating in bio-solid mechanics. Due to his experience with mechanical motion and structures, the majority of his focus has been, and will be with the motion of the bed, and the motors, actuators and controls used to move said bed. So far he has designed the scissor jack system, and calculated the required forces to lift the bed. This includes calculating tilting motion of the jack as the bed is lifted along an arch, as well as the rotational speed and torque required by the electric motor to provide the desired lifting speed and power.

21. Conclusion

The initial design is very similar to the optimal design which has been chosen. However, the one major component which has been changed continuously is the method with which the bed is lifted. Initially, the bed would be lifted by a hydraulic cylinder. However, this turned out to be overly noisy and had the potential to be unsanitary. The hydraulic system was replaced by an electric motor driving a linear actuator. This electric system would work mechanically identical to the hydraulic cylinder except in a quieter and cleaner fashion. This second design was a huge improvement to the hydraulic system, however the actuator required would be far too long to use practically. To compensate for this, a track with a screw in it would be used to drive a cart back and forth under the bed, which would push the bed up to the desired position. Once again, the track required would be far too long. In the optimal design, a scissor jack was implemented in much the same way as the linear actuator was in the second design. This allowed for the direct push-pull action on the bed, but less room is required for the scissor jack to operate under the bed since it collapses as it retracts.

The manner by which the lifting jack will be operated also evolved since the first design, but mostly due to the switch from hydraulic to electric. Initially, the control would call for multiple valves to be operated in order to vary the flow of the hydraulic system. However, once the system was changed to electric, a simple potentiometer and circuit could be used to vary the speed and direction of the electric motor. Additionally, this electric circuit allowed for the implementation of a safety switch which would break the circuit unless the bed was meant to be operated. Also, the handle its self was changed from a straight design to an S-shape which would be easier to operate as both a patient and a caretaker. In all, the optimal design offers the safest, cleanest and most reliable system to provide a variable speed and intuitive operation of an adjustable bed. Because of the easy operation, and minimal required force to operate, patients and caregivers of all ability levels and strength will find the ABAC adjustable bed the best choice for all applications.

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24. Appendix

24.1. Updated Specification

Electrical Parameters	
Voltage Input	120V AC
Voltage Operation	12V DC
Current Max	49A
Voltage Max	32V
Current Operation	max 15A
Fuse	20A
Environmental Parameters	
Operation Temperature	0-250˚ F
Storage Temperature	-50-250˚ F
Execution Speed	max 0.5 sec
Mechanical Input	1-20 lbs
Range of Motion	0-72˚
Compressed Scissor Jack Length	<6″
Extended Scissor Jack Length	20″

24.2. Purchase Requisitions and FAX quotes

Purchase Order	***Number***
Camping World – Scissor Jack	1
Digi-Key Corp. – Mosfets	2
Lee Spring – Compression Springs	3
The Home Depot – Bed Frame Supplies	4